# ELECTROMAGNETIC COMPATIBILITY
## - Compliance with Emerging Regulations


**By**

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# 1. Introduction

## *1.1 Motivation and Scope*

Over the past three years, Electromagnetic Compatibility (EMC) has emerged as a critical aspect of electrical and electronic design. In particular, this field of study has moved from being a specialist "stand alone" discipline undertaken by research institutes and the military to a topic that is of concern to everybody dealing with electrical/electronic products or services. The main impetus for this lift in profile has been the recent introduction of legislation concerning EMC which has been universally adopted by all member countries of the European Union (EU). This legislation, initially introduced in 1992, is referred to as "the EMC directive, 89/336/EEC" and is widely regarded as "the most comprehensive, complex and possibly contentious Directive ever to emanate from Brussels"[1]. The EMC Directive has not only unified the EMC requirements for trade throughout the European Union but has effectively led the way for EMC standards throughout the commercial world.

The main objectives of this thesis are to outline the basic principles of EMC, detail the requirements of the latest standards and associated testing techniques and to illustrate the issues that need to be addressed by design engineers in order to achieve EMC compliance. A practical and economical EMC test set up is documented and measurement results obtained from Switch-Mode Power Supply equipment are compared to fully calibrated measurements taken at a third party test house in order to determine the accuracy and thus usefulness of these "pre-compliance" test measurements.

## *1.2 What is EMC?*

Electro-Magnetic Compatibility or EMC is defined as "the ability of a device, unit of equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment"[2]. Thus there are two aspects associated with EMC:

1. The ability of electrical and electronic systems to operate without interfering with other systems. (ie. electromagnetic **emissions** must be limited)

2. The ability of such electrical and electronic systems to operate as intended within the electromagnetic environment in which it is installed (ie. the equipment must have an adequate level of **immunity** to electromagnetic disturbances)

### *1.2.1 Classic examples of electromagnetic incompatibility*

There is an ever growing list of examples of electromagnetic incompatibility from around the world. Some of these are amusing, many have resulted in dangerous situations and a few have been tragic. The following list outlines some reported examples with particular emphasis on Australian experiences.

- The use of some lap top computers on Australian domestic aircraft has caused interference and errors in navigational instruments (the use of lap tops is now strictly controlled on aircraft in Australia)

- The electronic locks on cell doors in a new Australian high security prison released whenever an RAAF F111 flew over (fortunately this was discovered and rectified before the prison was commissioned)

- The engine management systems of some makes of cars become disabled in close proximity to TV transmitter sites.

- The "accidental" operation of high powered naval radar in Sydney harbour set off hundreds of fire and burglar alarms in the harbour suburbs.

- Static discharges have caused loss of data and random cash draw openings on electronic point of sale cash registers.

- A faulty video recorder was found to be going into self oscillation periodically, transmitting via the TV aerial and blanking out a number of communications channels used by incoming international flights at Tullamarine.

- A popular musician, Tommy Emmanual, was unable to record using his favourite type of electronic guitar pick up due to conducted interference from a nearby industrial variable speed drive.

- The HMS Sheffield in the Falklands war was sunk with great loss of life when the missile warning system which would have detected the incoming Exocet missile was turned off because it interfered with the ship's satellite communications system.

### *1.2.2 Terminology*

There are various terms and "TLAs" (Three Letter Abbreviations) often used and interchanged in connection with EMC. Some of these include;

- RFI - Radio Frequency Interference

- EMI[i] - Electromagnetic Interference

- EMI[ii] - Electromagnetic Immunity

- RFS - Radio Frequency Susceptibility

Electromagnetic Compatibility encompasses all of these and is essentially concerned with electromagnetic emissions from equipment and susceptibility of equipment to various forms of electromagnetic disturbance.

### *1.2.3 The EMC Spectrum*

For the theorist, EMC deals with the electromagnetic spectrum "from DC to daylight" however the frequency range of most concern for the commercial world is limited to 150kHz to 1GHz. Various draft standards exist which consider frequencies both lower and higher but these were not published or well established at the time of writing.

The frequency range 150kHz - 30MHz which encompasses the broadcast AM radio band is generally measured and applied as conducted interference on connecting cables while the frequency band 30MHz - 1GHz which encompasses the broadcast FM radio and television bands, mobile phone communications, etc. is generally measured and applied as radiated interference through "free space".

### *1.2.4 The EMC Gap*

The aim of the European EMC directive and indeed the world wide enforcement of EMC standards is to maintain a notional gap between the level of emissions emanating from equipment and the level of immunity of equipment. Over the past 50 years or so, the transition from valves to transistors and finally to Integrated Circuits of increasing density and decreasing operating voltage levels has resulted in a steady decline in the immunity of electrical/electronic equipment to electromagnetic disturbances. This has been the source of great embarrassment to the US military who led the way in the 'high tech' arms race only to find that the older Soviet technology was far more immune to Nuclear Electromagnetic Pulse or NEMP events (a massive electromagnetic disturbance occurring as a result of a nuclear explosion). Consequently an extensive (and expensive) program was required to harden the more susceptible state of the art electronic assemblies (used in weapon and critical communication systems) against such electromagnetic disturbances.

In parallel with this decrease in electronic equipment immunity there has been a steady increase in the pollution and use of the electromagnetic environment as a result of the increase in communication services and the proliferation of digital electronics. The Information Technology Revolution in the past decade has given rise to a huge spread of equipment generating low level, high frequency, fast rise time signals which in turn are generating a widespread, broadband electromagnetic 'smog'[3]. This narrowing of the EMC gap is represented graphically in Figure 1.1

The aim of the enforcement EMC standards is to halt the convergence of emission and immunity levels, to maintain a suitable gap or margin and thus to allow equipment to operate satisfactorily in its intended environment.

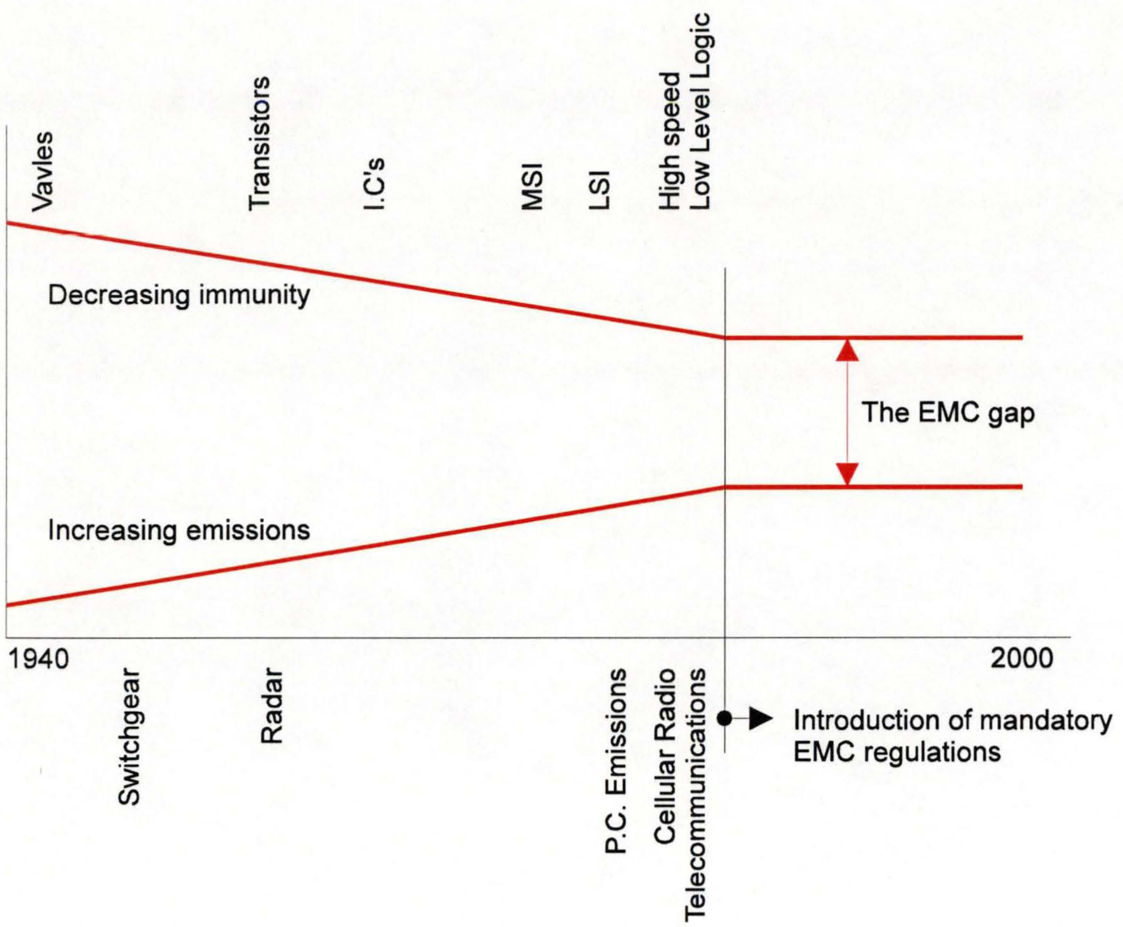


**Figure 1.1 - The EMC Gap**

## *1.3 Electromagnetic Interference - Sources and Areas of Concern*

Sources of electromagnetic interference can by divided into two classes;

1. Natural Sources (eg. lightning and solar effects)

2. Man-made sources (eg. electrostatic discharge, electrical and electronic systems and intentional spectrum users, nuclear electromagnetic pulse)[4]

### *1.3.1 Lightning*

Lightning is a natural phenomenon creating electromagnetic disturbances via a number of mechanisms. A thunderstorm occurs under certain meteorological conditions when electrical charge separation occurs within a cloud formation. Usually, the lighter positive charges separate to the top of the formation while the heavier negative charges separate to the bottom the bottom (the reverse is possible but rare). Lightning is an electrical discharge either between the oppositely charged regions within a cloud formation (cloud to cloud discharge) or between the lower region of the cloud and ground (cloud to ground lightning or ground strike). In the case of a ground strike, the charge separation in the cloud causes an increasing electric field to develop between the cloud and the ground. Eventually a "downward leader" of charge progresses from the thundercloud. This approaching leader of charge causes a rapid increase in the E-field between it and the ground. When a critical field strength value is reached (about 100m from ground) ground points launch "upward leaders". The first of these upward leaders to intercept the downward leader completes the lightning channel and the main discharge then occurs to this ground point. Often the same lightning channel conducts multiple strokes separated by tens to hundreds of milliseconds and this appears as the strobe like flashing associated with lightning. The peak currents associated with a lightning event vary between 10 and 200kA (typically 30 - 50 kA) for the first stroke and between 5 and 50kA (typically 15 - 20kA) for subsequent strokes. The rise times of these currents are in the order of 10μS for the first stroke and 0.25μS for subsequent strokes.

Lightning energy can be coupled into electrical systems in three ways;

1. Direct Strike: A direct strike to a building or communication antenna can introduce the full energy of the lightning stroke into one or more internal electrical systems.

2. Indirect Strike: A direct strike to utility power or communication lines some distance from a facility can introduce a proportion of the lightning energy into the connected electrical systems.

3. Induced: The large peak currents and fast rise times associated with a lightning event mean that the lightning channel itself radiates electromagnetic energy as if it were a large antenna transmitting an impulse. Thus, a nearby ground stroke can induce transients directly into electrical systems or onto utility power or telecommunication lines.

### *1.3.2 Solar Effects*

Solar activity may also result in electromagnetic interference which has a marked effect on the ionosphere. Radiation and high energy particles resulting from solar flare activity interact with the ionosphere and can have marked effects on communication systems which either transmit through the ionosphere (eg. UHF satellite communications) or use the reflective properties of the ionosphere for long distance transmission (eg. multiple hop HF communication).

### *1.3.3 Electrostatic Discharge (ESD)*

ESD is a phenomenon with which nearly everyone can identify. Walking on a synthetic carpet or moving in a plastic chair can cause the human body to become statically charged through the addition or removal of electrons. The potential associated with such a static charge can exceed 15kV. When a path to earth is encountered (eg. via an earthed metal equipment frame or the enclosure of a piece of electronic equipment) a discharge results which can be alarming for the person and can cause damage to electronic components in or near the discharge path.

Synthetic materials, such as nylon, are high in the "Triboelectric Series" and, as such, are particularly prone to causing the build up of static charge. In addition, the chances of building up an electrostatic charge are greatly enhanced in low humidity environments particularly where the relative humidity is below 35%. Both of these conditions are frequently encountered in modern office environments which have synthetic furnishings and air conditioning which often reduces the humidity below 35%.

### *1.3.4 Electrical and Electronic Systems:*

The unintentional pollution of the electromagnetic spectrum from electrical and electronic systems is an increasing problem. The recent increase in the profile of emission standards and legislation is an attempt to curb this problem before it becomes unmanageable. As mentioned already, the increase in the prevalence of digital switching equipment in the form of personal computers is one source of electromagnetic interference that is becoming more widespread. Other sources of interference include electrical machines (particularly Variable Speed Drives and DC machines with brushes), welders, switch mode power converters, induction heaters, power distribution and switching equipment, fluorescent lighting and switching noise from relays, contactors and solenoids.

### *1.3.5 Intentional Spectrum Users:*

For equipment designed to utilise particular frequency ranges of the electromagnetic spectrum for its intended operation, various regulating bodies exist to control the allocation of the spectrum and regulate its use. In Australia this role is adopted by the Spectrum Management Authority who act as spectrum watchdogs. Whilst some intentional spectrum users may become the source of electromagnetic interference through the emission of unintended frequencies or exceeding the nominated power levels under some circumstances, it is more common that these users of the spectrum are more concerned with interference from other sources disrupting their operation. The area where spectrum protection is of most concern is in broadcast and telecommunication services.

### *1.3.6 Nuclear Electromagnetic Pulse (NEMP):*

NEMP is a phenomenon which occurs as a result of a thermonuclear explosion whereby a huge electromagnetic pulse is generated which can cause currents in excess of 10kA to flow in metal structures and can effectively render most unprotected electronics useless. This is the area where electromagnetic interference is being used as a weapon, albeit only a threat that has not been used in anger to date, and, as such, is of particular concern to the defence forces.

### *1.3.7 Areas of Particular Concern for Electromagnetic Interference*

There are six main areas where the effects of electromagnetic interference give cause for concern[5]

1. Ignition and Detonation Hazards: Large metal structures may become a very efficient antennas at certain frequencies and sparking can result which is of particular concern in areas where a flammable atmosphere exists. In addition, there have been cases of premature detonation of electro-explosive systems due to

electromagnetic interference (eg. mobile transmitters and lightning strikes) and thus particular safeguards need to be implemented with such systems.

2. Spectrum Utilisation: The spectrum is becoming crowded due to the proliferation of communication services (in particular mobile phones) and thus cellular systems are being implemented to allow reuse of spectrum slots. Thus the number of intentional users of the spectrum is increasing as is the number of sources of unintentional emissions (eg. microprocessor based systems and personal computers).

3. Mains Supply Disturbances: The "quality of supply" for mains power is becoming more of an issue with the general trend to privatisation of power utilities. Disturbances on the mains supply fall within the scope of EMC with low frequency disturbances including voltage and frequency variation, brown outs and harmonic distortion of the voltage waveform. High frequency effects include lightning and switching transients, and radio frequency interference conducted via the mains conductors.

4. Malfunction of Electrical Based Systems: This is the symptom of inadequate EMC with which most people can identify. The examples of electromagnetic incompatibility given earlier are perhaps the more sensational cases but more "everyday" examples are experienced by many people (eg. CB radio interference with TV and stereo systems, loss of radio reception when cars drive under HV power lines and PC malfunctions due to electrical machine or welder operation). It is hoped that the new EMC regulations will minimise the cases of system malfunction due to electromagnetic effects by quantifying limits associated with the electromagnetic environment.

5. Data Security: Much of the technical expertise in the area of EMC has come from studies funded by defence programs to analyse the "TEMPEST" threat to communication systems. The aim of these studies was to eliminate low level "leakage" emissions from equipment inside secure facilities which may be intercepted and decoded. Also the security of information conveyed by analogue mobile phone systems has become an issue in recent times.

6. Biological Effects of Electromagnetic Radiation: This area of concern is a real "hot potato", particularly with respect to the effects of non-ionising radiation on the human body from sources such as overhead power lines and mobile phones. In terms of potential biological effects, the EM spectrum can be divided into four portions[6]. These are; the ionising radiation portion, where direct chemical damage in the form of bond breakage in DNA molecules can occur due to the high photon energy levels (X-rays, hard UV), the 'optical' non-ionising portion, where electron excitation can occur (soft UV, visible light, IR), the non-ionising portion where the wavelength is smaller than the body and heating via induced currents can occur (MW and higher RF) and finally the non-ionising portion where the wavelength is much larger than the body and heating via induced currents seldom occurs (lower RF frequencies and power frequencies). The heating effects on human cells due to emissions in the relevant portion of the EM spectrum are well understood but the non-thermal effects of non-ionising radiation and long term

exposure to power frequency magnetic fields are still to be quantified and questions are still being posed relating to links between cancer and living near power transmission lines. In addition, the longer term effects of close proximity of mobile phone emissions on the brain are yet to be determined, although there is a cynical view that a field study is currently being conducted involving millions of people across the world.

## *1.4 EMC Requirements in the Commercial World*

### *1.4.1 Who needs to know?*

Various national and international regulations for EMC are now coming into force. These are discussed in more detail later but the effect of these regulations is that every enterprise involved with the specification, design, manufacture, importation, installation or commissioning of electrical and electronic equipment will need to be aware of EMC issues and adopt measures to ensure EMC compliance. This awareness of EMC issues needs to permeate to every level of the company.

Research and Development staff involved with product design and development have an obvious need for EMC awareness at the design and prototype testing stage and naturally enough this is where EMC awareness usually starts within a company. However, EMC also involves;

- Production staff in how the product is constructed
- Installation and service personnel and authors of technical documentation in how the equipment is installed and maintained
- Testing, Commissioning and Quality Assurance personnel in ensuring EMC compliance for each unit
- Marketing and Sales staff in product marketing strategy and sales literature
- Senior Management in liability issues and maintaining company viability

### *1.4.2 EMC Awareness Summary*

The initial step in raising EMC awareness in an organisation is to distribute a summary outlining the EMC issues relevant to the various departments. Such a document enables each person in an organisation to identify what this "EMC stuff" means to them. Below is an example of such a summary applicable to small to medium sized companies. This also gives a useful overview of topics to be covered in more detail later.

*EMC Awareness Summary*

***General***

*What is EMC? - It is the ability of a device to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment. There are two aspects;*

*1. The electromagnetic **emissions** (particularly Radio Frequency Interference) from the device must be adequately limited.*

*2. The device must have an adequate level of **immunity** to electromagnetic disturbances (eg. transients, Radio Frequency fields and electrostatic discharges)*

*As of 1/1/96 all enterprises are legally required to "CE mark" any applicable product supplied to any country in the European Union (EU). There are some grey areas with respect to what products are applicable but there are marketing advantages in CE marking even when the applicability is in doubt. This has to be weighed up against the risk of penalty for inappropriately applying the CE mark.*

*Placing a "CE" mark on a product is a **self certification** that the product complies with all the relevant "directives" and can be sold into any EU country without being subject to any further technical trade restrictions. Whenever a CE mark is applied it **must** be accompanied by a Declaration of Conformity (DoC) stating what the equipment complies with. The directives relevant to most electrical/electronic manufacturing companies are;*

- *The Low Voltage Directive (LVD) for safety*
- *The EMC directive for Electromagnetic Compatibility*

*In addition other directives may apply to particular types of electrical equipment. These include;*

- *The Telecom Terminal Equipment (TTE) directive for PSTN connected equipment*
- *The Toy Safety Directive*
- *The Automotive Directive*
- *The Machine Safety Directive*
- *The Medical Devices Directive*
- *The Satellite Earth Station Equipment Directive*

*The TTE is an odd directive which calls up Common Technical Requirements (CTRs) and has been considered a disaster as a "new approach directive" as the CTR's usually call up national annexes which are specific to certain countries (ie. not uniform). The current plan is that the TTE is to be replaced by a new "CTE* *directive". Generally the EMC requirements called up in applicable CTR's take precedence over the requirements of the EMC directive.*

*Australia is introducing its own EMC framework which will mandate compliance and appropriate marking from 1/1/97. The Australian requirements are based on the emission requirements in the EU but there are no immunity requirements.*

***Management Issues:***

*CE marking and EMC compliance are classic issues requiring risk management. It is strongly recommended that for small to medium sized companies, the technical decisions and the management/marketing decisions should be made by separate people. Furthermore, the management/marketing decisions should be made by the DoC signatory who in turn should be at director level. The signatory can be the manufacturer or his authorised representative (eg. the importer in the EU).*

*Usually a senior electrical engineer or suitably qualified Quality Assurance manager fills the role of EMC coordinator and this should become a redundant role in the long term as EMC is adopted throughout the company.*

*It would also seem appropriate that the Chief Executive Officer or Technical Director in a small to medium sized company is in the best position to be the DoC signatory and have final say on business/risk issues acting on advice from the EMC coordinator and others. In signing a DoC, the signatory is stating that the apparatus complies with all relevant directives* ***not*** *necessarily that the apparatus complies with all relevant standards as standards is just one of the ways of demonstrating compliance with new approach directives. This allows for self certification without involving a third party or testing and permits a certain degree of flexibility in disputes which can work both ways*

*It should be highlighted that the ultimate sanction for non conformity is removal from the market and criminal sanctions (if used at all) will only apply to blatant intent to defraud. To date, no sanctions have been placed and no precedents have been set.*

*The degree of involvement of third parties is where risk management is required to balance the demonstration of due diligence and transferral of some liability against the risk of a dispute arising. It is like buying insurance where the costs are not only monetary but, in some cases time to market. This needs to be assessed on a case by case basis and the following three alternatives are offered as reasonable options. In order of decreasing risk, these are;*

1. *Self Certification based on in-house tests and engineering judgement. This would apply to very simple or low volume products.*

2. *Self Certification based on compliance with relevant standards (where available) and supported by NATA certified third party test reports. This process is made considerably faster and cheaper through in-house pre-compliance testing. A conservative estimate on the savings that can be made for a single complex product by having in house test equipment is $15 000. This estimate is based on statistics that*

*suggest that 80% of first time submissions for compliance testing fail and on average an untested product requires 2.5 test house iterations. (this alternative would be best for more complex or higher volume products where relevant standards can be identified)*

*3. Technical Construction File route involving assessment and certification by a Competent Body resident in the EU. This is the "non preferred" method which can be costly and may involve long delays but it is the most defensible alternative when applicable. This would apply to ranges of products for which no applicable harmonised standards exist, a large range of variants exist or volume and hence risk exposure is very high.*

***Marketing and Sales Issues:***

*The CE mark can be seen as a marketing tool for markets outside the EU where it will be perceived as a mark of international "quality". The issue of whether CE marking is valid/permitted revolves around an interpretation of whether a product is a component or apparatus with an intrinsic function and whether such apparatus is liable to cause or be affected by electromagnetic disturbances. This is a confusing issue which needs to be addressed on a case by case basis. The applicability and compliance of other directives such as the LVD and TTE directives also has to be addressed. If a product is CE marked when it does not fall into the scope of the directives, the existence and enforcement of sanctions varies between member countries. In practice, it is unlikely that action will be taken against inappropriately CE marked products provided that they do not violate any of the essential requirements of the directives. There are, however, good reasons for CE marking when in doubt as some countries (eg. France, who treat enforcement as a border issue and not applicable internally!) will not allow vaguely relevant goods to clear customs unless CE marked. This is also a good reason to apply the CE mark **both** to the product and to the packaging.*

*Copies of the DoC should be held by the importer/agent in the UK and should be in the native language of the relevant country (English, French and German should cover most but at the very least English should be supplied).*

***Purchasing and Production Issues:***

*The EMC characteristics of components and sub assemblies is in some cases critical and compliance may be affected if critical parts are substituted. In addition the way products are built (cable routing, tightening of fasteners and RF earthing points and commissioning methods) can all have effects on EMC compliance without obvious functional degradation.*

***Research and Development Issues:***

*Training of R&D design staff is required to cover the following EMC design issues;*

- *Grounding*
- *Screening*
- *Apertures*
- *Enclosure design*
- *Cable selection*
- *Cable termination*
- *Filters*
- *Suppressors*
- *Choice of configuration*
- *PCB layout*
- *Software design*

*In addition, testing issues need to be discussed and design procedures need to be established.*

***Capital Expenditure - In House Testing Facilities***

*In order for a small to medium sized company to become equipped for pre-compliance EMC testing, a capital outlay of some tens of thousands of dollars needs to be made. The author made an assessment of the needs for his company and purchased equipment with a total cost around $50k. Whilst the virtues of in house testing can be extolled and evidence provided to demonstrate that investment to date has already paid for itself, the level of test facility investment has been seen to be pitched at about the right level for cost effectiveness and only incremental improvements and additions should be required.*

### *1.4.3 The EMC Department*

As mentioned above, the propagation of EMC awareness in a company usually starts from the R&D or design department. As EMC has only recently become a strictly regulated requirement, a common practice is to nominate one person to become the EMC oracle in a company. In an ideal world this would be that nominated person's only task and would be taken on by an extensively trained EMC engineer who would head up an EMC department fully resourced with equipment and staff. In most small to medium sized enterprises however this is unrealistic and the reality is that the role of "The EMC Department" is usually taken on by an engineer as an "additional" task in his or her portfolio. In addition, the EMC "expert" often starts out with no specific training in the field and has to become an expert through self training, attending appropriate courses and hands-on experience.

The above situation was encountered by the author when he was nominated to be the company EMC expert (or should I say "bunny"). This thesis is essentially a summary of the author's experience and knowledge gained through training courses and seminars, information gathering, establishing rudimentary EMC test facilities on a limited budget and achieving EMC compliance for a number of new and existing designs.

# 2. EMC Regulations and Regulating Bodies

## *2.1 United States of America*

In the US, radio frequency interference is regulated by the Federal Communications Commission (FCC). The FCC is an independent government agency responsible for regulating inter-state and international communications by radio, television, wire, satellite and cable. The emphasis of the FCC is clearly on protection of communication services (historically - broadcast and telephone services). The other major player involved with EMC regulations in the USA is the Department of Defence. The Department of Defence Military Standards, MIL-STD-461 which covers the EMC requirements for military equipment and MIL-STD-462 which deals with measurement techniques are widely regarded as **the** international military standards for EMC. These military standards specify stringent limits and requirements and compliance testing is a complex and specialised procedure. This thesis concentrates on EMC requirements in the commercial world as the complexities of military EMC regulations is a study in itself, however an awareness of these important military standards is useful. Indeed, MIL-STD-461 (now at issue D) is regarded by many to be the grandfather of EMC standards and it is true to say that much of the EMC expertise available today has come from the military.

Other non military organisations specifying EMC requirements in the USA include;

- Food and Drug Administration (FDA) - regulates and controls the manufacturers (not the users) of electromedical devices. The FDA requires compliance with IEC 601 safety standards and EMI **immunity** in accordance with the relevant IEC 1000-4 standards.

- Society of Automotive Engineers (SAE) - regulates EMC issues for the automotive industry.

- American National Standards Institute and the Institute of Electrical and Electronic Engineers (ANSI/IEEE) - set EMC measurement and calibration standards (ANSI C63. series) and recommended practices to achieve EMC.

- Environmental Protection Agency (EPA) and the Office of Safety and Health Administration (OSHA) - regulating personal health and safety aspects of EMC.

### *2.1.1 History of FCC regulations*

The authority of the FCC to impose rules and regulations on industrial, consumer and commercial devices which may radiate electromagnetic energy originates from the US Communications Act of 1934. As communications equipment has become more complex and the spectrum become more crowded with radiation from commercial, consumer and industrial devices, the FCC has had to increase the scope and effectiveness of its regulations.

Early legislation only empowered the FCC to pursue the users of offending equipment who were often innocent third parties with limited technical knowledge. No constraints could be placed on the manufacturers and suppliers of such equipment. Furthermore, it was the manufacturer who was usually in the best place to rectify interference problems at the design stage.

Consequently changes in the legislation were made to extend the responsibility for EMI control from the users to manufacturers, importers and distributors. With this added muscle, the FCC could issue "Cease and Desist Orders" to any of the offending parties, obtain court injunctions or initiate prosecution proceedings[7].

The RFI requirements of the FCC are detailed in the "Code of Federal Regulations - 47" (CFR 47). Many of these regulations apply to radio transmitters and use of the spectrum for communication purposes. Part 15 "RF Devices" and Part 18 "Industrial, Scientific and Medical Equipment" address the issues of limiting EMI produced as a by-product of the operation of equipment. Part 68 which specifies rules and regulations for Direct Connection to the US Telephone Network is another part of the FCC Rules and Regulations often relevant to electro-technical equipment and often needs to be considered in conjunction with Part 15. Part 68 provides limits for hazardous voltage and current, signal power, line balance and protects the billing systems.

In 1990, Part 15 of these regulations was revised into a new format which distinguishes between intentional and unintentional radiators. The major impact of this revision was the inclusion of products incorporating digital devices as unintentional radiators (sub-part B).

Notably there are no mandatory immunity requirements proposed for non medical, commercial equipment in the US although the immunity requirements called up in MIL-STD-461 are extensive. The one immunity aspect that is addressed in ANSI standards and while not mandated by regulation is called up on many commercial specifications is immunity to Electro-Static Discharge (ESD).

### *2.1.2 FCC Rules and Regulations Part 15 (1990)*

As of 23/6/92, all applications for certification by the FCC must comply with the new revision of Part 15 of the regulations. This includes "digital devices" which are defined as any electronic device or system that generates and uses timing signals or pulses exceeding 9kHz and uses digital techniques. Two classes of equipment are defined; Class A which is intended for business, commercial or industrial use and Class B which is intended for residential use. Different emission limits apply to the two classes with the limits for class B equipment being the more stringent. Thus, as for CISPR limits, equipment complying with FCC Class A limits is restricted in its application and location while equipment complying with FCC Class B limits can be used without restriction. Clearly there is an incentive to meet Class B limits whenever possible.

The FCC emission limits are discussed in detail in chapter 3 and are generally similar in magnitude and frequency range to those specified in CISPR derived standards. A major difference with the FCC specification is an extension of the upper frequency of the measurement range beyond 1 GHz up to 40GHz depending on the highest clock frequency used in the equipment. The result of this is that equipment with clock frequencies exceeding 108MHz needs to be tested for emissions into the microwave range which can present testing problems.

### *2.1.3 Certification and Exemptions*

At the time of writing, the FCC rules and regulations were currently undergoing massive change with the passing of The Telecommunications Act of 1996 (as discussed below). The following is a summary of the certification requirements prior to the deregulatory changes brought about by this act.

Depending on the type of equipment, a manufacturer is required to obtain FCC certification or verify that the equipment meets the applicable technical requirements before it is placed on the market in the US. In practice, a relevant product used in the commercial or industrial environment must be **verified** as complying with FCC Class A limits. **Verification** requires a compliant report detailing all test results (including a description of EMC test facilities used and the FCC registration number), technical description of the apparatus and an attestation of compliance from a responsible person in the organisation responsible for marketing the product. This information is required to be kept on file for possible audit by the FCC. Personal Computers and associated digital devices to be used in domestic environments must be **certified** as complying with the tighter FCC Class B emission limits. **Certification** involves the same level of documentation as verification but this documentation **must be submitted to the FCC** who will issue an FCC ID number which must be affixed to the equipment along with a specified interference warning notice.

Exemptions from the FCC rules include digital devices used in transport vehicles (eg the automotive industry), industrial plant or public utility control systems, test equipment, digital devices used in an appliances, specialised medical computing equipment and very low power devices (consuming less than 6 nW). Sub-assemblies not sold to an end user are also exempt (eg. plug-in cards and Switch Mode Power Supplies). Plug-in computer cards sold to an end user are exempt if they do not have a connector for attaching external cables but are not exempt if they posses such a connector. In general, personal computers and peripherals require FCC type approval and **certification**. Such devices must be appropriately labelled to indicate compliance with Part 15 of the FCC rules and this labelling should include the FCC certification ID number where appropriate.

### *2.1.4 The Telecommunications Act of 1996*

On May 9$^{th}$, 1996 the Telecommunications Act was passed which introduced the most sweeping changes in the FCC Rules and Regulations since 1934. This act mostly deals with complete deregulation of the US telecommunications industry (particularly Common Carriers and CATV) but also deals with contentious issues such as censorship on the Internet. The motivations for this act were to increase competition and reduce prices, improve quality of telecommunication services in the US (I'll believe it when I see it!), introduce new services and new applications, make way for Personal Communications Services (PCS - International Wireless Roaming Gateway providing global, mobile personal phone/fax and Internet services) and generate billions of dollars in revenue by auctioning off the PCS spectrum.

As part of this deregulation strategy it is proposed to replace the existing certification procedure for digital devices with a self authorisation procedure. This was imminent at the time of writing. Under the proposed procedure, the manufacturer or responsible party would still be required to test equipment for compliancc with thc FCC rules, but would not be required to submit an application to the FCC. The present application form would be replaced by a Declaration of Conformity (DoC) issued by the responsible party declaring that the device has been tested and complies with the FCC rules. A notable difference between this approach and that adopted in Europe is that testing is mandated by the FCC (although under the new regime testing will be possible by an approved third party test house) whereas testing is not a requirement for CE marking.

This self certification is clearly a move to fall into line with the European EMC procedures. It is the intention that the FCC will continue to interface with international EMC developments and move towards world wide international harmonisation of EMC standards, EMC test methods and product approval procedures. This is happening already, with the FCC accepting RFI testing done to CISPR standards and limits In fact, as the CISPR limits are slightly more stringent than the corresponding FCC limits, the CISPR standards are becoming the defacto test standards in the US as these facilitate entry into both the US and European markets.

The FCC maintains an excellent Internet Web Site at (URL at time of writing was http://www.fcc.gov) and this is a good place to find up-to-date information as this new Telecommunications Act is implemented.

## *2.2 European Union*

As mentioned earlier, the recent introduction of EMC regulations in Europe has revolutionised the attitude of the commercial world to this performance aspect of electrical equipment. With the creation of the Single European Market came the requirement for free movement of goods between European states. At the outset each member country had its own requirements imposed on the manufacturers of goods for safety and other technical aspects (eg. EMC). These requirements presented technical barriers to trade and the Commission attempted to remove these barriers by introducing Directives which specified the requirements that equipment must meet to be freely marketed throughout Europe. This approach was unsatisfactory because it required all member states to agree on both the need for a directive and the detailed content of the standards required and unacceptable delays resulted. In 1985 the Council of Ministers adopted a "New Approach to Technical Harmonisation and Standards" and New Approach Directives came into being.

### *2.2.1 New Approach Directives*

New Approach Directives are limited to setting out the **essential requirements** which must be met before equipment can be marketed in the EU. The technical detail is not included in the directive but is to be specified in harmonised European Standards

(European Normatives - denoted EN ## ###). Products must comply with the essential requirements of any applicable Directives and compliance with applicable EN standards is the preferred way of demonstrating this compliance. Once a manufacturer declares compliance with the essential requirements of applicable new approach directives (indicated by "CE marking") then the product can be freely circulated throughout the EU and will not encounter any further "country specific" standards or approval technical barriers.

Obviously many different new approach directives are required to cover all possible product types. Listed below are the new approach directives (current or under consideration at the time of writing) which may effect some sectors of the electrical and electronic engineering industry[8];

- EMC directive (89/336/EEC)
- EMC amending directive (92/31/EEC)
- Telecommunications terminal equipment (91/263/EEC)
- Machinery safety (89/392/EEC)
- Medical devices (93/42/EEC)
- Active implantable electromedical devices (90/385/EEC)
- Toy safety (88/378/EEC)
- Satellite earth station equipment (91/263/EEC)
- Gas appliances (90/396/EEC)
- Non-automatic weighing machines (90/384/EEC)

The Telecoms Terminal Equipment (TTE) directive has generally been considered a disaster as a new approach directive. Compliance is based on regulations called Common Technical Requirements or CTR's which in some instances include specific national annexes thus defeating the philosophy of a new approach directive. A new directive called the Connected Telecoms Equipment (CTE) directive is now in draft form and is destined to replace the TTE directive. The CTE is designed to be a true "new approach directive" intended to relax the current telecoms type approval system and introduce universally accepted self assessment certification thus removing technical barriers to the trade of telecoms equipment within Europe.

Other non "new approach" directives important to electrical and electronics engineering based industries include;

- Low Voltage Directive (73/23/EEC)
- Automotive Directive (95/54/EC amending 72/245/EEC)

- Lift Safety (draft)
- Maritime equipment (draft)
- Civil avionics (Reg 3922.91)

Of these, the Low Voltage Directive or the LVD is perhaps the most widely applicable. The LVD (73/23/EEC) is concerned with safety of electrical equipment operating between 50 - 1000VAC or 75 - 1500VDC and is not a "new approach" directive. However the amendments introduced by the CE marking directive 93/68/EEC mean that the CE mark now denotes conformity with this as well as any other applicable new approach directive (a transition period of 1/1/95-1/1/97 applies for the LVD). The essential requirements of this directive is that products within its scope are "safe" or do not cause death or injury to people or animals nor cause damage to property. This covers all aspects of safety including risk of electric shock, mechanical failure, fire and explosion.

Compliance with the LVD can be demonstrated by compliance with (in order of priority);

- Harmonised European standards (EN)
- International standards (IEC)
- National standards (VDE, BS etc.)

Typical examples of applicable harmonised European safety standards for electrical equipment are shown below. These are generally copies or derivations of IEC standards (which are also being adopted as Australian standards).

EN60065 (IEC 65) - Household Electronic Apparatus

EN60335 (IEC 335, AS/NZS 3250) - Household and Similar Appliances

EN60950:1992 (IEC 950, AS/NZS 3260) - Information Technology Equipment

No third party assessment is required for compliance, only a self declaration and a technical file which describes the safety features of the product. Generally, third party assessment against an appropriate standard is obtained to minimise risk and spread liability as certified third party test reports contribute to a defence of due diligence.

### *2.2.2 The EMC Directive*

The EMC directive is a new approach directive, the essential requirements of which are described in Article 4, 89/336/EEC as follows;

**The apparatus shall be so constructed that;**

1. **equipment shall not generate electromagnetic disturbances exceeding a level allowing radio and telecommunications equipment and other apparatus to operate as intended;**

2. **equipment shall have an adequate level of intrinsic immunity from electromagnetic disturbances**

The directive is, in itself, simple but there are some grey areas involved with the scope of it's applicability.

The scope of the EMC directive is such that it covers all <u>apparatus</u> "liable to cause electromagnetic disturbance or the performance of which is liable to be affected by such a disturbance" which is either "placed on the market" or "taken into service". Apparatus refers to electrical and electronic appliances, equipment and installations. The strict definition of <u>apparatus/equipment</u> is *finished product with an intrinsic function, sold as a single functional unit.* The directive defines a <u>system</u> as *several items of apparatus combined to fulfil a specific objective and sold as a single functional unit.* An <u>installation</u> is defined as *several combined items of equipment or systems put together at a specific location to fulfil a specific objective but not sold as a single functional unit.* Under these definitions, <u>apparatus/equipment</u> and <u>systems</u> must be declared compliant while only the constituent parts of an <u>installation</u> must be declared compliant.

Specific exclusions from the EMC directive include;

- apparatus whose EMC aspects are wholly covered by other directives (eg. the TTE directive)

- apparatus for use in a sealed electromagnetic environment (eg. electron microscopes)

- military equipment

- second hand apparatus and spare parts

- installations comprising individually compliant apparatus and systems

- self-built amateur radio apparatus

- simple or benign apparatus (eg. a light bulb)

- components not intended for the end user or which do not have an intrinsic or <u>direct</u> function

Perhaps the main area of contention is between components (which may be excluded) and apparatus (which is included in the scope of the directive). This issue is addressed in detail in [9]. The extremes are easy to define. A passive component such as a resistor or capacitor does not fall within the scope whereas a personal computer clearly does. There are numerous examples which fall into a grey area in between. The two criteria to consider are;

1. What is the route to market?

2. Does the item have a direct function applicable to the end user?

If all of the production of a device is sold to another manufacturer for inclusion into another assembly then the manufacturer of the device is excluded while the manufacturer of the assembly needs to make a declaration. However, if **any** of the devices are sold directly to the end user through either direct marketing or through commercial outlets then the manufacturer must make a Declaration of Conformity (DoC).

The second criteria, relating to "direct function" is more complex. Due to the confusion arising from the component versus apparatus issue, the commission in Brussels published a set of guidelines in April 1996 in which it was spelt out that components providing a direct function were included in the scope of the EMC directive. This concept of "direct function" is defined as adding a new function or functionality (eg. CD ROM drives or plug-in PC cards).

Even with these "clarifying" guidelines, there is still confusion relating to this discrimination and interpretations of specific cases differ from one "expert" to the next. It would seem that if any valid argument can be made that a component or subassembly provides some extra function or feature to a piece of apparatus or system and is offered for sale as an item to the end customer then it should be considered to be under the scope of the directive and treated accordingly. The risk to be evaluated is one of inappropriately CE marking a "component" (which is prohibited by law in some countries, such as the United Kingdom) versus the risk of not CE marking a device that may be regarded by some to be within the scope of the directive (which is universally prohibited by law). There are also marketing advantages of CE marking if possible.

The directive also specifies that it applies to apparatus that is "placed on the market" or "taken into service". "Placed on the market" is the ***first*** <u>making available</u> of every individual, physically existing finished product in the EC by the manufacturer, importer or his authorised representative. This clearly excludes second hand equipment. Apparatus is "taken into service" when it is <u>used</u> for the ***first*** time by its end user. Thus apparatus built for "in-house" use but not placed on the market is clearly within the scope of the directive and must meet the essential requirements (although such apparatus does not require a Declaration of Conformity or CE mark).

The amending directive 92/31/EEC was introduced to allow a transition period of four years from 1992 (when the EMC directive was to have become legally binding) to the end of 1995. This period was to allow breathing space for harmonised standards to be made available and for manufacturers to phase in EMC design features. This is now history, with compliance with the EMC directive mandated by law as of the 1$^{st}$ January 1996.

### *2.2.3 Routes to Compliance*

In order to determine compliance with the EMC directives two "routes to compliance" are specified. The preferred method (ie. that intended for the majority of cases) is **self certification** to harmonised European standards. This is often termed "The Standards Route" and the steps involved are listed below;

1. The responsible party judges compliance of the product against selected harmonised standards. Testing against those standards is not mandatory but obviously provides the greatest degree of confidence. The assessment options available in order of decreasing levels of certainty are; third party certified tests, in-house tests and engineering judgement.

2. A Declaration of Conformity is made (see following section)

3. A CE mark is applied and the product is marketed.

This does not **require** the involvement of any third party nor approval or external review by any agency or body in Europe. Assessment against standards has the added advantage of clearly defined goals or specification for compliance.

Self certification may only be made against harmonised (EN) standards which have been published in the Official Journal (OJ) of the European Commission. There are four types of EMC standards; basic standards which define measurement methods, generic standards which define the minimum requirements for the EMC Directive based on operating environment classification (these can be universally applied unless the intended environment is specialised), product family standards which define the requirements for specific product sectors and product standards which define the requirements for specific products. In general basic standards are not published in the OJ but generic, product family and product specific standards are.

The second (non preferred) route to compliance is the Technical Construction File (TCF). In cases where the nature of the apparatus precludes the application of standards, there are too many variants of the apparatus for testing of each to be practical (eg. more than ten), the apparatus is too large or extensive to test or the apparatus has already been tested to non-harmonised standards then the TCF route can be adopted. The steps involved with the TCF route are;

1. A preliminary TCF is constructed and submitted to a **"Competent Body" resident in the EU**

2. The Competent Body reviews the TCF and may carry out some testing or request more information and, when satisfied, issues a report/certificate stating that if equipment is built according to the details in the TCF then it will be compliant with the essential requirements of the EMC directive.

3. The manufacturer then makes a Declaration of Conformity and maintains the TCF for the next ten years

4. A CE mark is applied and the product is marketed.

The key item in the TCF route to compliance is the mandatory involvement of an accredited Competent Body resident in the EU. While this is an added hindrance in most cases, there are some circumstances where the security provided by a third party validation (and shared liability) is reason enough to opt for the TCF route.

When used the TCF should contain the following as a minimum;

- identification of the apparatus or series of variants
- a technical description of the apparatus
- a rationale for using the TCF route and the procedures used to ensure conformity
- details of EMC specific design elements
- any relevant test results obtained
- a signed report or certificate from a Competent body indicating compliance

Regardless of which route is used, the Directive applies to every individual, physically existing finished product and so some quality control and sample testing should be adopted to ensure continuing conformity. In order to demonstrate the measures used to achieve this "internal production control" the manufacturer (or his authorised representative) is required to keep a set of "technical documentation" at the disposal of the national authorities for a period of ten years after the last product has been manufactured. This "technical documentation" is different to the TCF (usually a subset of a TCF) and is more aptly called a "compliance folder" in the Australian EMC Framework terminology described later.

This technical documentation or compliance folder should contain the following (as appropriate);

- product description and identification
- design and manufacturing drawings
- technical description of products construction and operation
- details of standards applied and design measures taken to achieve compliance
- results of design calculations and examinations carried out
- test reports
- measures taken to ensure continuing compliance (quality control, sample testing etc.)
- a copy of the Declaration of Conformity

It should be noted that most of the above information is normally kept as part of the design documentation for the product but the information required here is that relating specifically to EMC issues.

### *2.2.4 The CE mark and the Declaration of Conformity*

Once a product is determined to fall within the scope of the directive and compliance has been ascertained the supplier or manufacturer is required to make a Declaration of Conformity (DoC) and affix a "CE" (Community European) mark to the product and/or its packaging, instructions or guarantee. The form of the CE mark as illustrated in Figure 2.1 is carefully specified. It must be at least 5mm high and must be affixed "visibly legibly and indelibly".

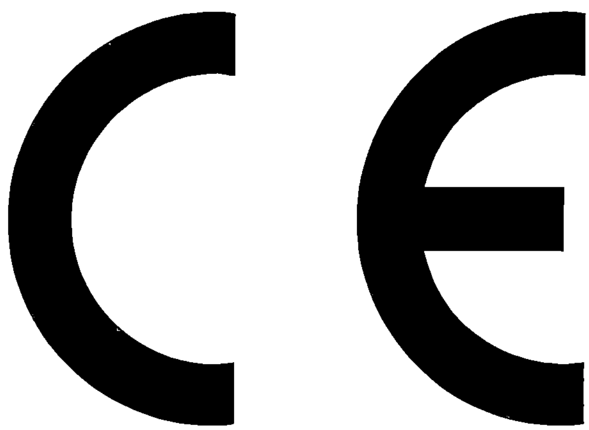

**Figure 2.1 The CE Mark**

Placing the CE mark on a product signifies that it complies with **all** applicable new approach Directives. Thus a CE mark on an electrical toy signifies compliance with the Toy Safety Directive **and** the EMC directive. CE marking will be required for (and will apply to) products falling within the scope of the Low Voltage Directive (discussed above) from the 1/1/97.

The CE mark is intended to be a universal mark indicating that a product meets certain minimum requirements and should therefore be allowed free passage into the EU or between member states without being subject to any further technical trade barriers. It is important to realise that the CE mark is essentially a customs mark to allow free passage of goods and is **not** a "customer mark" intended to indicate product quality. Unfortunately this distinction has been blurred and the presence of the CE mark is being regarded as a mark of a quality product. Indeed it is possible to produce items which are completely ineffective at their primary function but which are eligible to be CE marked.

When ever the CE mark is applied to a product a Declaration of Conformity (DoC) **must** be completed. The DoC is an important legal document which must be kept available **in the EU** for a period of ten years after the apparatus is placed on the market.

The DoC must contain the following;

- The name and address of the organisation making the declaration (this can be the manufacturer from inside or outside the EU or the importer in the EU)
- A description of the apparatus to which it relates (enough to uniquely identify the product)
- The name and address of the manufacturer (this need not be the same as the declarer)
- Details of the published European Normatives with which compliance is claimed
- Identification and signature of an officer of the company (someone empowered to bind the resources of the company)
- The date of issue

It is important to note that the DoC can be made by a manufacturer or on-seller from outside the EU but needs to be available to the relevant authorities in the EU. This usually means that a copy needs to reside with an agent or importer in the EU and many parties are supplying copies of the DoC with the product to avoid customs delays. The standards which are referenced must be European Norms published in the Official Journal (OJ) of the European Commission and the Directive does not specify **testing** to these standards only that the product must conform. Thus a DoC may be made on the basis of engineering judgement, in-house pre compliance testing **or** third party testing by an accredited laboratory. The decision of which approach to take is a risk management one where the risk of the product not complying needs to be considered in conjunction with the demonstration of "due diligence" should a legal challenge arise.

An example of a DoC for a 1kW DC-DC converter is included for reference.

### *2.2.5 Enforcement*

The issue of enforcement of the EMC directive is left up to the governments of the individual member states who must have a defined procedure in place. While criminal sanctions are a possibility, it is expected that fines and/or jail sentences (if imposed at all) will only apply to blatant intent to defraud. The ultimate sanction intended for enforcement of the EMC directive is "removal from the market". The intended enforcement efforts vary widely between the EU countries. The Department of Trade and Industry (DTI) in the UK have indicated that its enforcement efforts will be complaint driven. This will include investigation of complaints of incompatibility arising from actual use of equipment and complaints of non compliance regardless of whether there is actual problem in service. This latter form of complaint is expected to come from competitors "shopping" other manufacturers to the authorities and thus it is expected that the electrical/electronics industry will keep itself honest.[10] Germany on the other hand intend to introduce random spot checks and already have a network of 54 offices and 100 staff employed by the BAPT for "market observation". France is

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ISO 9002 QUALITY ASSURED FIRM SGS

# DECLARATION OF CONFORMITY

## in accordance with EN 45 014 and IEC Guide 22

The following responsible parties;

**Manufacturer's Name**: Global Lightning Technologies Pty. Ltd.
A.C.N. 009 538 729

**Manufacturer's Address**: Innovation Drive,
Technopark, Dowsings Point,
Tasmania, Australia 7010

**Importer's Name**:

**Importer's Address**:

certify that the equipment described below conforms with the essential protection requirements of Council Directive 89/336/EEC (the EMC Directive) as amended by Directives 92/31/EEC and 93/68/EEC and conforms with the requirements of Council Directive 73/23/EEC (the Low Voltage Directive) as amended by Directive 93/68/EEC.

**Type of Equipment:** **DC - DC Converter**
**Product type:** **CONVERTEC HPC 1000/48-24**
**48VDC - 24VDC, 1000W**

**Standards applied**:
(supported by NATA test reports - for details refer to product information)

**Safety:** **EN 60 950 : 1992**

**EMC:** **EN 50 081-1 : 1992**
**EN 50 082-1 : 1992**

(name of authorised officer)

.............................................................. ..............................................................
(signature of authorised officer) (date of issue)

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intending to treat enforcement as a border issue with goods not being allowed to clear customs without a CE mark and DoC (notably this does not apply to French domestic products!). Other examples include Belgium who will have similar procedures to the UK and Sweden who is establishing a dedicated enforcement authority. To date no sanctions have been enforced and thus no precedent has been set with a "softly, softly" approach being encouraged by the EC in these early days.

## *2.3 Australia*

Australia is in the process of introducing an "EMC Framework" which is very closely linked to some of the essential requirements of the European EMC Directive. Initially this framework will concentrate on setting mandatory limits on radio frequency interference (emissions) from equipment in "commercial, residential and light industry" environments (ie. most electro-technical products). It is intended to extend the interference aspects of the framework to include limits on harmonics and voltage fluctuations but this depends on cooperation from relevant electrical safety regulatory authorities and no date has yet been set for these future inclusions.

Electromagnetic immunity standards will apply only on a voluntary basis for most products. Mandatory immunity compliance will only be applied in limited cases related to public safety and consumer protection, where products have a high degree of susceptibility to RF emission levels, particularly levels relating to mobile communications.[11] This "watered down" approach to immunity standards is the major difference between the Australian EMC framework and the European EMC Directive which mandates compliance with essential immunity requirements.

### *2.3.1 The Spectrum Management Agency*

The primary responsibility for the framework rests with the Spectrum Management Agency (SMA). The SMA is a Commonwealth Agency which was established in 1993 under provisions of the Radiocommunications Act 1992. The SMA is broadly responsible for the management of the radio frequency spectrum and this includes, planning the overall use of the spectrum, licensing access to the spectrum, managing the pricing of access, setting standards for equipment which uses the spectrum, managing electromagnetic interference and promoting Australia's spectrum interests internationally.[12]

### *2.3.2 Other Regulatory Agencies*

Other agencies covering specific product areas will formulate complementary standards to be incorporated in the EMC framework. The other agencies with a role in EMC management and their areas of responsibilities are detailed below;

- Therapeutic Goods Administration-: responsible for the EMC immunity of listed and registered electromedical and implantable electromedical devices.
- Federal Office of Road Safety-: responsible for road vehicle EMC issues.
- Civil Aviation Authority-: responsible for avionics and aviation ground facilities.

- AUSTEL-: responsible for EMC of telecommunications apparatus and satellite earth station equipment (soon to be merged with the SMA).

EMC requirements determined by these agencies take precedence over any general EMC requirements specified by the SMA. The EMC framework established by the SMA is intended to set minimum standards.

### *2.3.3 Compliance*

Compliance with the requirements of the EMC framework is demonstrated in a similar manner to that detailed above for compliance with the essential requirements of the European EMC directive. The two "routes" for compliance are virtually identical to those outlined for CE marking ie. via testing of products against applicable primary standards and preparation of a compliance folder or via the preparation of a Technical Construction File (TCF). It is the responsibility of suppliers (manufacturers or product importers) to ensure that the technical requirements of the EMC framework are met before a product is first placed on the market in Australia (as of January 1997). Detailed guidelines for compliance are provided by the SMA in a public document titled "Electromagnetic Compatibility Framework - Information for Suppliers"(11).

There are four steps involved with meeting the technical requirements of the EMC framework;

1. Establish valid technical grounds for product compliance.

2. Prepare a compliance folder or TCF.

3. Make a Declaration of Conformity (DoC).

4. Apply appropriate labelling to the product.

The EMC compliance model as outlined by the SMA is illustrated in Figure 2.2

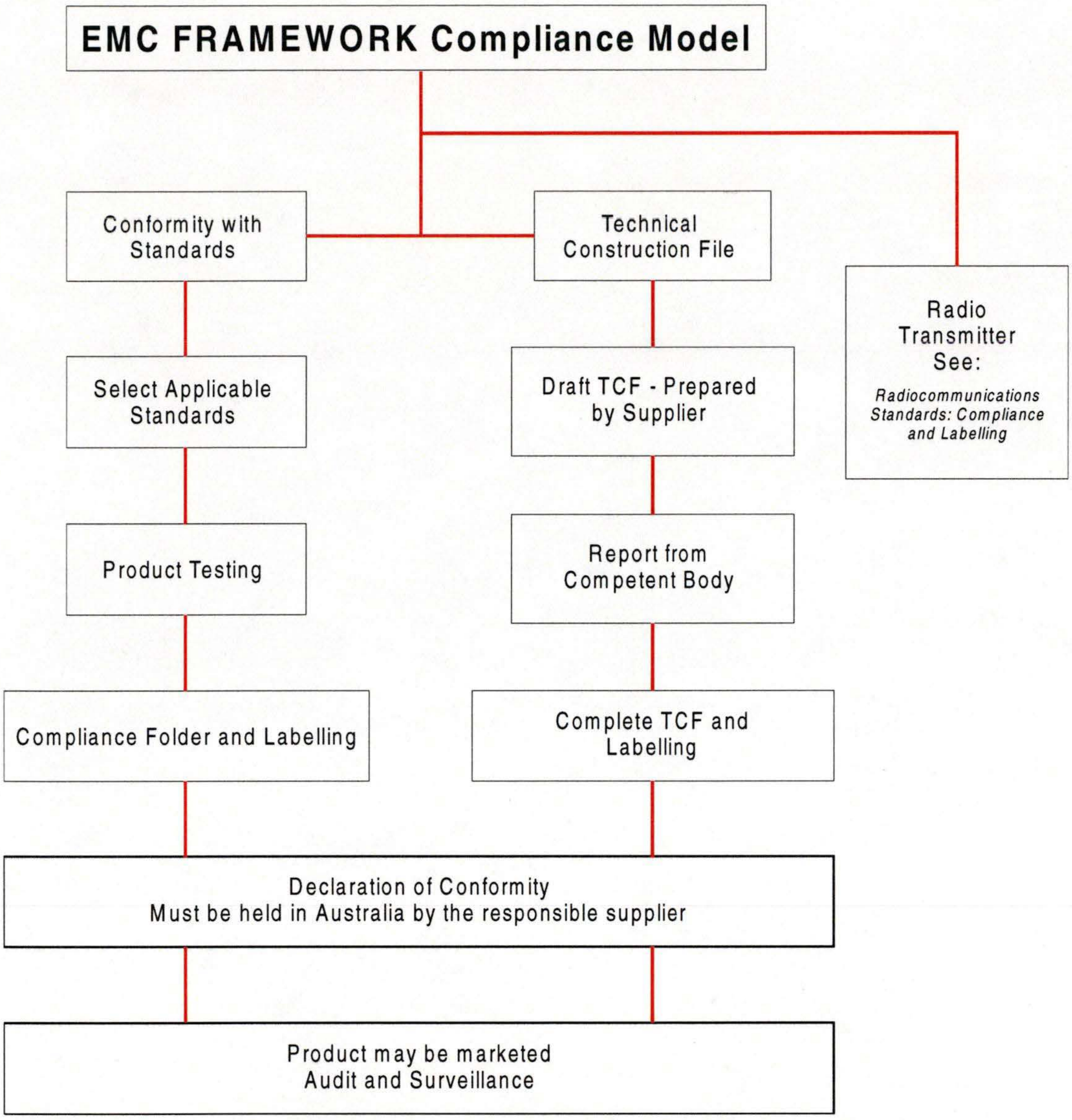


**Figure 2.2**

The content of the DoC is similar to that required for CE marking and needs to include test results, details of any special operating or installation conditions required for compliance and details of manufacturing conditions and quality control procedures used to ensure continuing compliance.

A compliance folder should contain the following;

- Test reports (third party or in-house)
- A signed DoC
- A description of the apparatus including a photograph and block diagram
- Reference to specifications for conformity
- Technical description of the apparatus

When utilised a TCF should contain;

- a description of the apparatus
- a technical rationale for the use of the TCF route
- a summary of EMC design steps taken and standards applied in part or in full
- all technical reports relevant to the product
- any reports issued by the competent body
- a signed DoC

Part of the requirements for product compliance is that it must be appropriately labelled to indicate EMC compliance and provide a traceable link between a device and the supplier responsible for placing it on the Australian market. It was originally intended that a 'universal' mark called the Regulatory Compliance Mark (RCM) be used for this purpose as well as to indicate compliance with appropriate electrical safety requirements, AUSTEL requirements and any other compliance regulations for the majority of products (in a similar vein to the CE mark). Unfortunately, agreement on some issues relating to safety compliance could not be reached and so at the time of writing it was proposed that the 'C-tick' mark be used to indicate product compliance with the EMC framework and AUSTEL requirements only. The 'C-tick' mark is "owned" by the SMA and an application must be made for a company to use it. The mark must be contiguous with one of four standard formats of supplier identification;

1. The registered name and address of the place of business
2. The Australian Company Number (ACN)
3. A trademark registered in
4. A supplier code issued by the SMA

The 'C-tick' mark is shown in Figure 2.3 and an example of its use with a supplier identification code in a format approved by the SMA is shown in Figure 2.4.

**Figure 2.3 - The 'C-tick' mark**

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**Figure 2.4 - Format of the 'C-tick mark with a supplier identification code**

*2.3.4 Enforcement*

The SMA proposes to audit compliance documentation on a random basis. Where deficiencies are found, three randomly selected samples of the product may be required to be submitted to a competent body for evaluation. Where non-compliance with relevant standards is evident, the supplier may be subject to prosecution under the Radiocommunications Act 1992. The SMA also has powers to seize or demand that non-conforming equipment be disconnected until those non-conformances have been rectified. Further amendments to the act are proposed to include penalties and punitive fines related to the volume of sales of non-conforming products.

The SMA will investigate complaints where a product subject to mandatory EMC standards is suspected of causing interference related to radiocommunications. If such interference was found to be occurring, a formal audit of compliance documentation would then be undertaken.

## 2.4 International

### 2.4.1 NAFTA, EU and East Asia

Considering the world scene, three major, technology intensive, trading blocks are emerging, namely, the European Union (EU), North American Free Trade Agreement (NAFTA) countries and the East Asian countries. Obviously other large markets for electrotechnology exist with China and Russia being two examples of huge "stand alone" markets in their embryonic stage but these type of markets tend to be less regulatory and standards driven. From an EMC point of view, the NAFTA countries are clearly aligned with the FCC requirements while EU is leading the way in EMC regulations with the EMC directive. Countries within the East Asian region are tending to align themselves with the European requirements (at least in part) and it is likely that "CE" marking will be seen as a desirable feature of electro-technical specification throughout this trading block. Australia and New Zealand will most probably become part of this "East Asian" grouping and the recently introduced EMC framework may well become a blueprint for EMC requirements within this region.

### 2.4.2 Global Trends

While there is some criticism of the European EMC requirements with some saying that the immunity requirements are becoming too onerous and extensive for commercial products, it is widely accepted that the basic CISPR and IEC standards referenced in relation to the European EMC Directive will undoubtedly become the Global standards for EMC. This is already happening in the US where the FCC are accepting test results to the CISPR standards which have tighter limits than those specified in the FCC Rules and Regulations Part 15.B. Thus the CISPR standards are becoming the de-facto US standards as they generally satisfy the testing requirements for two large markets. There may yet be a convergence of the ANSI C63.2 and C63.4 standards and the CISPR standards as the measurement range of the CISPR standards extends out to embrace the complete 9kHz - 40GHz spectrum.

Japan has a non-government industry body called the Voluntary Council for Control of Interference (VCCI) which is charged with setting voluntary EMI emission standards. Although these standards are broadly termed "voluntary" the market is such that compliance is effectively mandatory. The VCCI in Japan is another example of an EMC regulatory body which calls up the IEC/CISPR basic EMC standards.

New Zealand was investigating harmonisation of its EMC regulations with the Australian EMC framework at the time of writing. A Trans-Tasman Mutual Recognition Agreement (MRA) was on the drawing board which included EMC compliance. New Zealand has had an EMC regime in place for some time with the Ministry of Commerce (MOC) taking on the regulatory role. New Zealand has also adopted CISPR/IEC standards and the regulatory procedure involves declaring compliance (DoC) against an appropriate standard and registering the declaration with the MOC (with the appropriate fee). There is no mandatory marking required for New Zealand although the C-tick mark may be applied after the MoC has given its consent. The MoC carries out random audits of declared products listed on its computer database and the audit generally requires the submission of the test report used to declare compliance.

Thus it can be seen that the world is waking up to EMC issues and mandating compliance of products through various regulatory bodies. In general the IEC/CISPR standards are becoming **the** global commercial EMC testing standards and these are investigated in detail in the next chapter. The other standards body having input into the global commercial EMC scene is the American National Standards Institute (ANSI) and the relevant ANSI standards are also discussed.

# 3. Relevant Standards

## *3.1 EMC Standards Organisations*

### *3.1.1 IEC/CISPR*

As mentioned previously, the most widely acknowledged EMC standards available are those produced by the IEC and the special IEC technical committee, CISPR. The International Electrotechnical Commission (IEC) works in cooperation with the International Standards Organisation (ISO) and has more than 41 member countries. Countries are represented by national committees which are intended to represent all of the electrotechnical interests of that country. The actual standards development work is carried out by technical committees and sub-committees which address particular product sectors. The IEC's overall objective is to "to promote international cooperation on all questions of standardisation by issuing publications and recommendations in the form of international standards which the national committees are expected to adopt with minor amendment as national standards.[13] Two IEC Technical Committees are dedicated full time to EMC standards work namely, TC77 - *Electromagnetic Compatibility between Equipment Including Networks* and the Comite International Special Des Perturbations Radioelectriques (CISPR) which translated from French to English reads as "the International Special Committee on Radio Interference".

CISPR was set up in 1934 with the objective of reaching world wide agreement on control of radio interference thus avoiding barriers to trade (this commendable goal is still being strived for today with the recent introduction of the EMC directive in the EC being the most positive step for many years). CISPR's concern is RFI in spectrum from 9kHz to 18GHz. It is a special IEC Technical Committee in that it is made up of the normal national representative from IEC member countries as well as representatives of amateur radio, the automotive industry, the electrical distribution industry among others.

TC77 is charged with producing "basic" EMC standards (outside the scope of CISPR) for use by product standards committees. The core standards being developed by TC77 are those contained in the IEC 1000 series. Some of these (in the IEC 1000-4 series) are based on existing standards such as the IEC 801 series and the IEC 555 series with an extension of their scope beyond industrial and process control. It is expected that CISPR and IEC 1000 standards will continue to co-exist. The Advisory Committee on EMC (ACEC) is charged with coordinating the work of the IEC Technical Committees to ensure that duplicate or contradicting standards are not produced.

It should be noted that CISPR and IEC standards have no legal standing and need not be adopted by individual national committees. That said, there is generally wide acceptance of IEC/CISPR standards as true "international standards" and the progression to national acceptance or to CENELEC endorsed EN standards is often "automatic". By way of example, Australia and New Zealand have a policy of adopting IEC/CISPR standards as they become available. These joint standards are prefixed AS/NZS.

CENELEC (French acronym for the European Organisation for Electrotechnical Standardisation) and has been charged by the European Commission to produce standards necessary to show conformity with the EMC directive. The Technical Committee involved with the preparation of European EMC standards is TC110 and various sub-committees and working groups exist to create standards which are not available from other sources. Whenever CISPR or IEC standards exist, CENELEC adopts these rather than "re-inventing the wheel". CENELEC produces standards prefixed by EN (European Normative) or HD (Harmonised Document). An EN must be adopted verbatim by the various national standards organisations whereas an HD must be adopted with its technical content and intent maintained. CISPR and IEC standard numbers are incorporated in the EN numbering scheme in the following way;

| | | |
|---|---|---|
| IEC XXX | becomes | EN 60XXX |
| IEC YYYY | becomes | EN 6YYYY |
| CISPR ZZ | becomes | EN 550ZZ |

Thus when you know the "code", it is possible to identify which IEC or CISPR standard is equivalent to a given EN. Generic emission and immunity standards developed by TC110 have an EN 50XXX format for the CENELEC standard number.

A useful source of information on current CENELEC standards and technical committee organisation and activity is the Internet Web Site maintained by APPROVAL magazine (URL at time of writing was http://www.compulink.co.uk/~approval/).

### *3.1.2 ANSI/IEEE*

The American National Standards Institute (ANSI) and the Institute of Electrical and Electronics Engineers (IEEE) are the organisations responsible for setting EMC standards in America. Standards are developed by the IEEE who act as a technical body and secretariat and are adopted by ANSI as ratified national standards. The complete collection of Electromagnetic Compatibility Standards was published by the IEEE in February 1996 and this includes all EMC related IEEE standards and the ANSI 63. series of approved national standards. These standards predominantly relate to electromagnetic emissions but there are references to electromagnetic immunity requirements such as electrostatic discharge testing. Measurement techniques, methods of test site characterisation, specifications for instrumentation and recommended practices for choosing limits are all covered in detail. The standards dealing with instrumentation and test site characterisation (ANSI C63 parts 2,5,6 and 7) are particularly comprehensive and recognised internationally as important source documents.

The key EMC and EMC related ANSI standards are summarised below;

ANSI C62: Surge Protection Devices

ANSI C63: EMC

- C63.2 - Noise and Field Strength Instrumentation (9kHz to 40GHz)
- C63.4 - Methods of Measurement of Radio-Noise Emissions from Low-Voltage Electrical and Electronic Equipment (9kHz to 40GHz)
- C63.5 - Calibration of Antennas used for Radiated Emission Measurements
- C63.6 - Computation of errors in Open Area Test Site Measurements
- C63.7 - Guide for the Construction of Open Area Test Sites
- C63.12 - Recommended practice for EMC Limits
- C63.13 - Application and Evaluation of EMI Power Line Filters
- C63.16 - Guide for Electrostatic Discharge Test Methodologies

ANSI C95: Radiation Hazards

Of the above, ANSI C63.4 is perhaps the most important as this is the standard approved and referenced by the FCC as the method of measurement of radio frequency devices (including unintentional radiation) under Part 15 of CFR 47 (as discussed in Chapter 2).

### *3.2 Emission Standards:*

A cross reference of identical or similar key EMC emission standards is shown in Table 3.1. Such a table is nearly always out of date or incomplete as soon as it is drawn up but the list shown here was current at the time of writing and covers the most important source standards. EN standards shown in italics have been published in the Official Journal of the European Community (OJEC) and thus may be referenced on a Declaration of Conformity for the EMC directive. Entries shown in bold are considered by the author to be the essential EMC emission standards and are connected directly or indirectly to generic standards. These important standards are summarised below. Note: More detail on EMC testing terminology and techniques is given in later chapters;

### 3.2.1 **CISPR 14:1993** - *Emissions from household and similar electrical apparatus*
(EN 55014:1993, AS/NZS 1044:1995)

*Title*

Limits and methods of measurement of radio interference characteristics of household electrical appliances, portable tools and similar electrical apparatus.

*Other Equivalents*

BS800, VDE0875 part 1

*Scope*

Electrical household appliances, portable tools under 2kW and other electrical equipment causing similar types of continuous or discontinuous interference, including regulating controls under 25A incorporating semiconductor devices.

Specifically excluded is; apparatus covered by other standards and power supplies to be used separately.

*Tests*

Mains terminal disturbance voltage 148.5kHz (150kHz) to 30MHz measured using a 50Ω/50μH CISPR 16 artificial mains network; less stringent limits for portable tools and the load terminals of regulating controls. Average as well as quasi peak measurements are required. Discontinuous interference (clicks) must also be measured at spot frequencies for appliances which generate such interference through switching operations.

Interference power from 30MHz to 300MHz on mains lead, measured by means of the absorbing clamp; regulating controls incorporating semiconductor devices excluded.

### 3.2.2 **CISPR 22:1993** - *Emissions from Information Technology Equipment*
(EN 55022:1995, AS/NZS 3548:1995)

*Title*

Limits and methods of measurement of radio interference characteristics of information technology equipment.

*Other Equivalents*

BS6527,VDE0871 part 3, FCC CFR 47 Part 15.B - ANSI C63.4:1992 (Similar)

*Scope*

Equipment whose primary function is either (or a combination of) data entry, storage, display, retrieval, transmission, processing, switching or control, and which may be equipped with one or more terminal ports typically operated for information transfer, and with a rated supply voltage not exceeding 600V.

Class A equipment is for use in typical commercial establishments; Class B equipment is suitable for use in domestic establishments (tighter emission limits).

*Tests*

Mains terminal interference voltage, quasi-peak and average detection from 150kHz to 30MHz measured using 50Ω/50μH CISPR artificial mains network.

Radiated interference field strength using quasi peak detection from 30MHz to 1000MHz measured at 10m on an open area test site.

Measurements are also required on telecommunications signal ports, of conducted current over the range 150kHz to 30MHz..

### *3.2.3* ***IEC 1000-3 parts 2 and 3*** *- Power supply disturbances from mains powered equipment*

(EN 61000-3 parts 2 and 3 - derived from IEC 555-2,3)

*Title*

Disturbances in supply systems caused by electrical and electronic equipment having an input current up to 16A and intended to be connected to public low-voltage distribution systems, part 2 : Harmonics, part 3: voltage fluctuations.

*Equivalents*

IEC 555-2,3 (source standards), EN 60555-2,3 BS5406, VDE0838

*Scope*

All electrical and electronic equipment having an input current up to 16A and intended to be connected to public low-voltage distribution systems.

*Tests*

Part 2: measurement of 50Hz harmonic currents up to 2kHz using a wave analyser and current shunt or transformer.

Part 3: measurement of voltage fluctuations using a flickermeter or by analytical methods.

*Limits*

Part 2: present version has absolute limits in amps applying to each harmonic from n=2 to 40. Proposed amendment divides equipment into four classes depending on its type and power rating and applies different limits to each. This amendment is still the subject of much controversy.

Part 3: limits apply to magnitude of maximum permissible percentage voltage changes with respect to number of voltage changes per second or per minute.

### *3.2.4* ***EN 50081-1:1992*** *- Generic Emission Standard, Domestic - Commercial Environment*

(AS/NZS 4251.1 - 1994)

*Title*

Generic emission standard, part 1: Domestic, commercial and light industry environment.

*Scope*

All apparatus intended for use in the residential, commercial and light industrial environment for which no dedicated product or product-family emission standards exist.

<u>NB</u> equipment installed in the residential, commercial and light industry environment is considered to be directly connected to the public mains supply or to a dedicated DC source. Typical locations are residential properties, retail outlets, laboratories, business premises, outdoor locations etc.

Note: This is the more stringent of the generic emission standards as it is expected that apparatus which is the most sensitive (or susceptible) to electromagnetic emissions is expected to exist in this type of environment (eg. broadcast receivers).

*Tests*

Enclosure: radiated emissions from 30 to 1000MHz as per CISPR 22 Class B; applicable only to apparatus containing processing devices operating above 9kHz.

AC mains port: conducted emissions from 150kHz to 30MHz as per CISPR 22 Class B

Discontinuous interference on AC mains port measured at spot frequencies as per CISPR14, if relevant.

Mains harmonic emissions measured as per IEC 555-2 (IEC 1000-3-2)

<u>NB</u> an informative annex references tests which will be proposed for inclusion in the standard when the relevant reference standards are published. This includes tests on signal, control and DC power ports: conducted current from 150kHz to 30MHz as per amendment to CISPR 22 (essentially measuring conducted interference currents using a current transformer).

### *3.2.5* ***EN 50081-2:1994*** *- Generic Emission Standard, Industrial Environment* (AS/NZS 4251.2 - under consideration)

*Title*

Generic emission standard, part 2: industrial environment

*Scope*

Apparatus operating at less than 1000V rms AC intended for use in the industrial environment, for which no dedicated product or product-family immunity standard exists, but excluding radio transmitters.

NB equipment installed in the industrial environment is not connected to the public mains network but is considered to be connected to an industrial power distribution network with a dedicated distribution transformer.

*Tests*

Enclosure: radiated emissions from 30 to 1000MHz as CISPR 11 (Similar to CISPR 22 but with some specific "ISM" frequencies allowed to be utilised)

AC mains port: conducted emissions from 150kHz to 30MHz as per IEC/CISPR 11 (similar to CISPR 14); impulse noise appearing more often than 5 times per minute must comply with CISPR 14.

NB an informative annex references tests which will be proposed for inclusion in the standard when the relevant reference standards are published. This includes tests on signal, control and DC power ports: conducted emissions from 150kHz to 30MHz as per amendment to CISPR 22.

# Table 3.1 - Emission Standards

| Subject/Title | International | European | USA & Other | Australian & New Zealand | Comments (re: Australia) |
|---|---|---|---|---|---|
| **Industrial, Scientific and Medical** | CISPR 11 (1990) | *EN 55011 (1991)* | FCC CFR-47 | AS/NZS 2064 (1992) | Changed frequency limits |
| **Vehicle Ignition Systems** | CISPR 12 (1990) | ECE Reg. 10 | SAEJ551 (1990) | AS/NZS 2557 (1992) | No variation from CISPR |
| **Radio and TV Receivers** | CISPR 13 (1990) | *EN 55013 (1990)* | CFR-47 Part 15 | AS/NZS 1053 (1992) | No variation from CISPR |
| **Household Appliances** | **CISPR 14 (1993)** | ***EN 55014 (1993)*** | **German VDE0875** | **AS/NZS 1044 (1995)** | **No variation from CISPR** |
| **Fluorescent Lamps and Luminaries** | CISPR 15 (1992) | *EN 55015 (1993)* | | AS/NZS 4051 1992 | Under dispute from industry |
| **Measurement Methods** | **CISPR 16 (1987)** | | **ANSI C63.4 (1992)** | **AS/NZS 1052.1 (1995)** | **No variation from CISPR** |
| **Overhead Power Lines** | CISPR 18 -1 (1982) -2 (1986) | | ANSI 430 | AS 2344 (1980) | Pre-dates CISPR 18 - under review |
| **Microwave Ovens** | CISPR 19 (1983) | | | AS/NZS 4052 (1992) | No variation from CISPR |
| **Information Technology Equipment** | **CISPR 22 (1993)** | ***EN 55022 (1995)*** | **FCC CFR-47 Part 15.B German VDE0871** | **AS/NZS 3548 (1995)** | **No variation from CISPR** |
| **Out of Band ISM emissions** | CISPR 23 (1987 report) | | CFR-47 Part 18 | | |
| **Signalling on Low Voltage Installations** | | *EN 50065-1 (1992)* | | | |
| **Generic Emission: Residential, Commercial and Light Industry** | | ***EN 50081-1 (1992)*** | | **AS/NZS 4251.1 (1994)** | **No variation from EN** |
| **Generic Emission: Heavy Industry** | | ***EN 50081-2 (1994)*** | | **under consideration** | **AS/NZS 4251.2 expected to be identical to EN** |
| **Disturbances in mains supply by Household and Similar Apparatus (Harmonics and Voltage Flicker)** | **IEC 1000-3-2 (1995) (IEC 555-2) IEC 1000-3-3 (1994) (IEC 555-3)** | ***EN 61000-3-2 (1995) (EN 60555-2) EN 61000-3-3 (1995) (EN 60555-3)*** | | **AS 2279 AS 2279.1 AS 2279.2** | **Based on IEC and ESAA Australian requirements - under review** |

Note: EN = European Standard (Normative)
ENV = European Pre-standard
pr (DD) ENV = draft European Pre-standard
pr ETS = draft ETSI Standard
HD = Harmonisation Document

### *3.3 Immunity Standards:*

A cross reference of identical or similar key EMC immunity standards (similar to that given for emission standards) is shown in Table 3.2. As before, EN standards shown in italics have been published in the OJEC and thus may be referenced on a Declaration of Conformity for the EMC directive. Entries shown in bold are considered by the author to be the essential EMC immunity standards. These standards are summarised below:

#### *3.3.1* ***IEC 1000-4****: EMC basic immunity standards*

(derived from the IEC 801 series)

*Title*

Electromagnetic compatibility for electrical and electronic equipment.

*Equivalent*

IEC 801 (source standard) HD 481, BS 6667, VDE 0843

*Scope*

The susceptibility of electrical and electronic equipment to:

Part 2: electrostatic discharge generated by operators and between objects in close proximity (eg. from friction between synthetics in low humidities)

Part 3: radiated electromagnetic energy (eg. from mobile radio transceivers or mobile phones)

Part 4: repetitive electrical fast transients (eg. from noisy contactors or solenoid switching)

Part 5 (draft): surges caused by overvoltages/currents from switching and lightning transients (eg. from direct or indirect lightning strikes to exposed power feeds)

Part 6 (draft): conducted radio frequency disturbances (eg. pick up from broadcast transmitters)

<u>NB</u> The scope of the IEC 801 series covered only industrial-process measurement and control equipment and this has been extended in the IEC 1000-4 series of ‘basic’ EMC standards to include all electrical and electronic equipment.

### *3.3.2 **IEC 1000-4-2:1995** - Electrostatic Discharge (ESD)*

(EN 61000-4-2:1995 - derived from IEC 801-2)

*Tests*

At least ten single discharges to preselected points, accessible to personnel during normal usage, in the most sensitive polarity. Contact discharge method to be used unless this is impossible, in which case air discharge used. Also ten single discharges to be applied to a coupling plane spaced 0.1 from the EUT.

*Limits*

Severity levels from 2kV to 15kV (8kV contact discharge) depending on installation and environmental conditions.

### *3.3.3 **IEC 1000-4-3:1995** - Radiated RF Field*

(DD ENV 50140:1994 - derived from IEC 801-3)

*Tests*

Radiated RF field generated by antennas in a shielded anechoic enclosure, or by a stripline or TEM cell swept from 26MHz to 1000MHz at 1.5 x $10^{-3}$ decades/s with the EUT in its most sensitive orientation. The most recent revision of this standard increased the upper frequency from 500MHz to 1GHz and required that the RF signal be 80% amplitude modulated at 1kHz.

*Limits*

Severity levels of 1, 3 or 10V/m (or greater) depending on the expected EMR environment.

### *3.3.4 **IEC 1000-4-4:1995** - Electrical Fast Transient Bursts (EFT)*

(EN 61000-4-4:1995 - derived from IEC 801-4)

*Tests*

Bursts of 5ns/50ns pulses at a repetition rate of 5kHz with a duration of 15ms and period of 300ms, applied in both polarities between power supply terminals (including the protective earth) and a reference ground plane, or via a capacitive coupling clamp onto I/O circuits and communication lines.

*Limits*

Severity levels of 0.5, 1, 2 and 4kV on power supply lines, and half these values on signal, data and control lines, depending on the expected environmental and installation conditions.

NB a proposed amendment incorporating a 100kHz pulse repetition frequency has met with some opposition.

### *3.3.5* ***IEC 1000-4-5:1995*** *- Transient Surges*

(DD ENV 50142:1995 - derived from draft IEC 801-5)

*Tests*

At least 5 positive and 5 negative surges of 1.2/50μs voltage or 8/20μs current waveshape surges from a surge generator of 2Ω output impedance, line to line on ac/dc power lines; 12Ω output impedance, line to earth on ac/dc power lines; 42Ω output impedance, capacitively coupled line to line and line to earth on I/O lines.

*Limits*

Severity levels of 0.5, 1, 2 and 4kV, depending on environment and type of installation.

### *3.3.6* ***IEC 1000-4-6:1995*** *- Conducted RF disturbances*

(DD ENV 50141:1994 - derived from draft IEC 801-6)

*Tests*

RF voltage amplitude modulated 80% at 1 kHz swept at 1.5 x $10^{-3}$ decades/s over the frequency range 150kHz to 26MHz and 26MHz to 230MHz, applied via coupling/decoupling networks to each cable port of the EUT.

NB applicability of tests over the frequency range 26MHz to 230MHz overlaps with IEC 801 part 3 and may be used instead of the tests specified in that document, depending on the EUT dimensions.

*Limits*

Severity levels of 1, 3 or 10V/m emf depending on the EMR environment of final installation.

### *3.3.7* ***EN 50082-1:1992*** *Generic Immunity Standard, Domestic - Commercial Environment*

(AS/NZS 4252.1-1994)

*Title*

Generic immunity standard, part 1: domestic, commercial and light industry environment.

*Scope*

All apparatus intended for use in the residential, commercial and light industrial environment for which no dedicated product or product-family immunity standards exist.

*Tests*

Electrostatic discharge to enclosure as per IEC 1000-4-2 (IEC 801 part 2), at 8kV (air discharge) - at least performance criteria B recommended.

Radiated RF field from 27MHz to 500MHz as per IEC 1000-4-3 (IEC 801 part 3), at 3V/m - Performance Criteria A recommended.

Electrical fast transients 5/50ns common mode as per IEC 1000-4-4 (IEC 801 part 4), applied to all I/O and power ports with some exceptions, amplitude 0.5 or 1kV dependent on type of port and method of coupling - at least performance criteria B recommended.

NB an informative annex references tests which will be proposed for inclusion in the standard when the relevant reference standards are published. This includes:

- magnetic field, 50Hz at 3A/m
- extension of RF radiated field to 80 - 1000MHz AM
- pulsed RF field, 1.89GHz at 3V/m
- inclusion of contact discharge ESD at 4kV
- conducted RF common mode voltage on all I/O and power ports, 150kHz to 100MHz at 3V, as per IEC 1000-4-6 (draft IEC 801 part 6)
- AC 50Hz common mode voltage of 10V on signal and control lines
- supply voltage deviations, interruptions and fluctuations on supply ports
- surges on AC power ports, 1kV differential mode, 2kV common mode as per IEC 1000-4-5 (draft IEC 801 part 5).

NB the applicability of many of the above tests depends on the allowable length of line that may be connected to the port in question.

*Performance Criteria*

Three performance criteria for tests results are proposed:

- Criteria A - the apparatus continues to operate as intended with no degradation below a performance level specified by the manufacturer;
- Criteria B - the apparatus continues to operate as intended after the test, but during the test some degradation of performance is allowed;
- Criteria C - temporary loss of function is allowed, provided that it is self- or operator-recoverable.

Depending on the function and purpose, any of these may be considered as appropriate by the manufacturer and a rationale for the minimum performance criteria that is acceptable should be given in the test plan and final report.

### *3.3.8 **EN 50082-2:1994** - Generic Immunity Standard, Industrial Environment*
(AS/NZS 4252-2: under consideration)

*Title*

Generic immunity standard, part 2: industrial environment.

*Scope*

Apparatus operating at less than 1000v rms AC intended for use in the industrial environment, for which no dedicated product or product-family immunity standard exists, but excluding radio transmitters.

Note: This is the more stringent of the generic immunity standards as the severity level of electromagnetic phenomena is generally higher in an industrial environment.

*Tests*

Electrostatic discharge to enclosure as per IEC 1000-4-2 (IEC 801 part 2), at 8kV (air discharge) pr 4kV (contact discharge).

Radiated RF field from 27MHz to 500MHz as per IEC1000-4-3 (IEC 801 part 3), at 10V/m.

Electrical fast transients 5/50ns common mode as per IEC 1000-4-4 (IEC 801 part 4), applied to all I/O and power ports, amplitude 1 or 2kV dependent on type of port and method of coupling.

<u>NB</u> an informative annex references tests which will be proposed for inclusion in the standard when the relevant standards are published. This includes:

- magnetic field, 50Hz at 30A/m

- extension of RF radiated field to 26 - 1000MHz
- pulsed RF field, 1.89GHz at 3V/m
- conducted RF common mode voltage on all I/O and power ports, 150kHz to 100MHz at 3V or 10V depending on type of port, as per IEC 1000-4-6 (draft IEC 801 part 6)
- AC 50Hz common mode voltage of 10V or 20Vrms depending on type of port, on signal and control lines
- supply voltage deviations, interruptions and fluctuations on supply ports
- surges on AC power ports, 2kV differential mode, 4kV common mode as per IEC 1000-4-5 (draft IEC 801 part 5)

NB the applicability of many of the above tests depends on the allowable length of line that may be connected to the port in question.

*Criteria*

The same performance criteria used in part 1 are referenced in this standard.

# Table 3.2 - Immunity Standards

| Subject/Title | International | European | USA & Other | Australian & New Zealand | Comments (re: Australia) |
|---|---|---|---|---|---|
| **Radio & TV Receivers** | IEC CISPR 20 (1996) | *EN 55020* | | AS/NZS 4053 (1992) | No variation from IEC |
| **Mobile Radio** | IEC CISPR 21 (1985 report) | ETS 300 279 (1996) | | Radiocomms (1992) | |
| **Household Appliances** | draft IEC CISPR 14 - 2 | *EN 55104* (EN55014-2) | | | |
| **IT Equipment** | IEC CISPR 24-2<br>IEC CISPR 24-3 | pr EN 55024-2,3 (1994) | | under consideration | |
| **Generic Immunity: Residential, Commercial & Light Industry** | | ***EN 50082-1 (1992)*** | | **AS/NZS 4252.1 (1994)** | **No variation from EN** |
| **Generic Immunity: Heavy Industry** | | ***EN 50082-2 (1994)*** | | **under consideration** | **AS/NZS 4252.2 expected to be identical to EN** |
| **Basic Immunity Standards** | **IEC1000-4 series (derived from IEC 801 series)** | | **ANSI C63 Series** | | |
| • **ESD** | **IEC 1000-4-2 (1995)** | **EN 61000-4-2 (1995)** | **C63.16** | | |
| • **Radiated RF** | **IEC 1000-4-3 (1995)** | **DD ENV 50140 (1994)** | **VDE0847 Series** | | |
| • **EFT burst** | **IEC 1000-4-4 (1995)** | **EN 61000-4-4 (1995)** | | | |
| • **Transient Surge** | **IEC 1000-4-5 (1995)** | **DD ENV 50142 (1995)** | | | |
| • **Conducted RF** | **IEC 1000-4-6 (1995)** | **DD ENV 50141 (1994)** | | | |
| • **Power Freq. Magnetic Fields** | IEC 1000-4-8 (1993) | EN 61000-4--8 (1993) | | | |
| • **Pulse Magnetic Fields** | IEC 1000-4-9 (1993) | EN 61000-4-9 (1993) | | | |
| • **Damped Osc. Magnetic Fields** | IEC 1000-4-10 (1993) | EN 61000-4-10 (1993) | | | |
| • **Voltage Dips, Breaks and Variations** | IEC 1000-4-11 (1994) | EN 61000-4-11 (1994) | | | |
| • **Oscillatory Waves** | IEC 1000-4-12 (1995) | EN 61000-4-12 (1995) | | | |
| **Industrial Process Control and Measurement Equipment** | IEC 801 series | HD 481 (1987)<br>EN 60801 (1993) | | | |

### *3.4 Specific EMC Standards*

Some examples of "product family" general EMC standards are given in Table 3.3. These standards specify, the equipment configuration to be used for testing, the phenomena to be addressed and set appropriate limits and performance criteria to be met. They do not generally specify EMC test techniques but refer to those detailed in the "basic" emission and immunity standards discussed previously.

## Table 3.3 - Examples of Product Specific EMC Standards

| Subject/Title | International | European | USA & Other | Australian & New Zealand | Comments (re: Australia) |
|---|---|---|---|---|---|
| **Electromedical Equipment** | IEC 601-1-2 (1993) | *EN 60601-1-2 (1993)* | | AS/NZS 3200.1.2 (1995) | No variation from IEC |
| **Road Vehicles** | ISO DIS 11452 | | | | |
| **AMPS receivers** | | pr ETS 300279 | | AS/NZS 4295 (1995) | based on Dept. of Transport and Comms. |
| **Hearing Aids (RF immunity)** | IEC 118 - Under Development | | | AS/NZS 1088.9 (1995) | based on NAL research |
| **Uninterruptible Power Supply Systems** | | *EN 50091-2* | | | |
| **Programmable Controllers** | | *EN 61131-2* | | | |
| **ISDN Terminal Equipment** | | pr ENV 55102 | | | |
| **Cable TV Distribution Systems** | | EN 50083-2 | | | |

### *3.5 Which Standard?*

This is the question that many industries and manufacturers are beginning to ask (with some exasperation). The need for standards to place limits on emissions from equipment is almost universally accepted and welcomed by most. The need for widespread enforcement of immunity standards, outside specific safety critical fields such as the automotive and electromedical industries, is a contentious issue.

The recent proliferation of electromagnetic immunity tests has been largely driven by the technocratic German input to IEC standards and is essentially an adoption of VDE standards. The proposed inclusion of many of these new immunity tests in the generic immunity standards is causing many to cry "enough". In the future, more product and product family specific EMC standards will emerge which will call up a subset of the established basic EMC standards and reference only those electromagnetic phenomena that are relevant to that type of equipment. Thus, there will be a move away from the use of the generic standards which will specify more onerous "catch all" requirements and towards specific product based EMC standards.

# 4. EMC Design Techniques

The scope of design techniques for achieving EMC is extensive and each technique is a field of study in its own right. Thus, it is not possible to do justice to any of these techniques in a single chapter such as this. The following sections are aimed at introducing each of the main areas involved with "Designing for EMC" in order to give the reader some guide for further investigation. Indeed there are complete texts available on each of these areas with the volumes written by Donald White being one good starting point[14]. Design approaches cover a broad range of design disciplines and thus the EMC aware engineer needs to have an understanding of each of the following areas as well as detailed knowledge of his/her own field of expertise;

- electrical/electronic circuit design
- mechanical enclosure and packaging design
- PCB layout design
- software design

The following EMC design topics are presented with an emphasis on concepts, rules of thumb and practical key thoughts rather than a rigorous theoretical treatment.

## *4.1 Grounding*

Correct grounding (or earthing) is possibly the most important factor in achieving EMC compliance. The important concept to grasp when considering grounding from an EMC perspective is that ground, be it a network of tracks on a circuit board, a metal chassis or a wire, needs to be considered as a **return current path** with an impedance and corresponding voltage drops rather than an equipotential point or "zero potential" reference conductor. The practice of drawing earth symbols all over an electrical schematic is misleading as this promotes the idea that ground is some magical equipotential current sink, which at higher frequencies it never is.

Grounding fundamentals[15];

- All earth conductors and conducting networks have a finite impedance which increases with frequency (ohms law V=IR extended to V=IR - Ldi/dt).
- No two separate ground points are at the same potential unless there is no current flow between them.
- It is not possible to achieve "single point earthing" at high frequencies.

It is important to realise that to achieve good <u>immunity</u> to electromagnetic phenomena the high frequency performance of circuits designed to operate a low frequencies or DC needs to be considered - a point often overlooked by designers.

An essential tool for EMC design of equipment is a **ground map.** This is essentially a plan showing all ground reference points and return current paths with other circuit details omitted or reduced to block diagram level. This should include ground paths formed by enclosure and chassis structures, cable screens, PCB tracks and planes and wiring for signal returns and safety earthing. This "ground map" should be carefully maintained and monitored throughout the design procedure with EMC in mind.

When considering the return path through the grounding network, a designer needs to ensure minimum ground path impedance and carefully manage the ground current flow generated by both internal and external electromagnetic phenomena. Some specific applications of this fundamental design principal are covered under other topics outlined in this chapter.

### *4.2 Screening*

Screening or shielding is another fundamental EMC design technique. The basic principle of screening is illustrated in Figure 4.2.1 and essentially involves using a conductive barrier to prevent internal electromagnetic fields from escaping and external electromagnetic fields from penetrating. This can take the form of enclosing a piece of apparatus in a conductive case or identifying critical, sensitive or noisy sections of circuitry and employing local shielding around these areas. The best enclosure from an EMC point of view is a welded metal box with no apertures, joints, seems or cable penetrations. Clearly this is impractical and many other factors including ergonomics, cost and functional and thermal design, are involved in the choice of enclosure for a product. The enclosure designer must however factor in EMC as an important design requirement which must be given due consideration. Extra constraints on enclosure design for EMC which are covered in other sections include, ensuring conductive continuity (at RF) across seams and joints, restriction of aperture size and orientation and allowing for appropriate interfaces for incoming and outgoing cables.

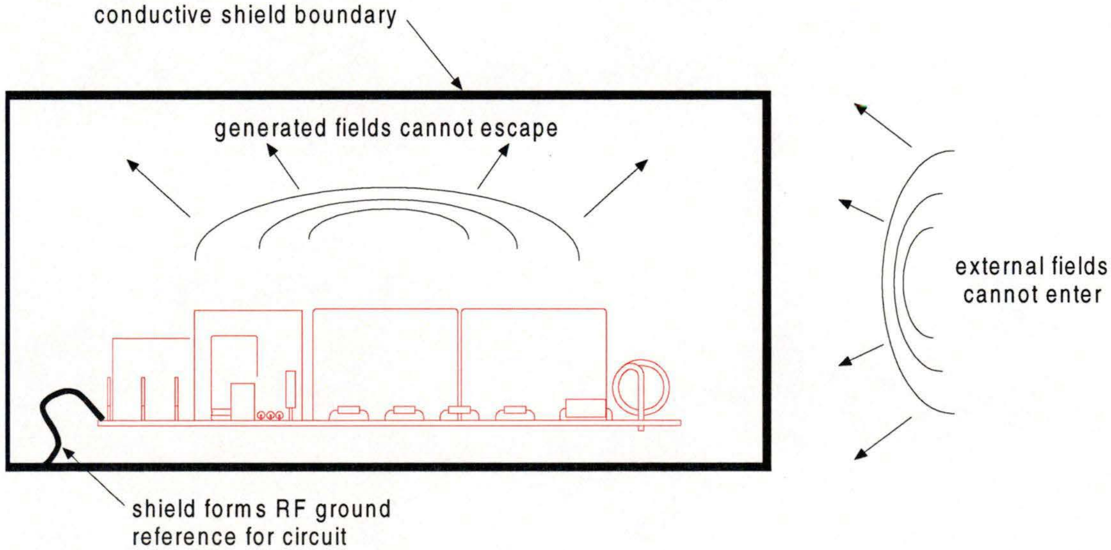



**Figure 4.2.1 - The Concept of Shielding**

Local shielding of sensitive or noisy sections of circuitry is another technique which can be employed but this usually requires that allowance be made for partitioning of such circuitry at the initial design stage as retrofitting such shields is usually impractical.

### *4.3 Apertures*

Figure 4.3.1 shows a typical enclosure for a piece of apparatus. Even when a metal box is used for the enclosure, apertures in that box are necessary for the various functional reasons indicated. Shielding effectiveness is an aspect of EMC on which a great deal of study has been done and it can be shown that for most frequencies of concern, simple sheet metal boxes without seams or apertures give a shielding effectiveness much greater than 100dB. This figure is really only academic because when the necessary apertures and joints are introduced into the case, these tend to dominate and greatly reduce the shielding effectiveness of the enclosure. In general, the thickness of a conductive screen is of secondary importance when compared to the effect of apertures and seams.

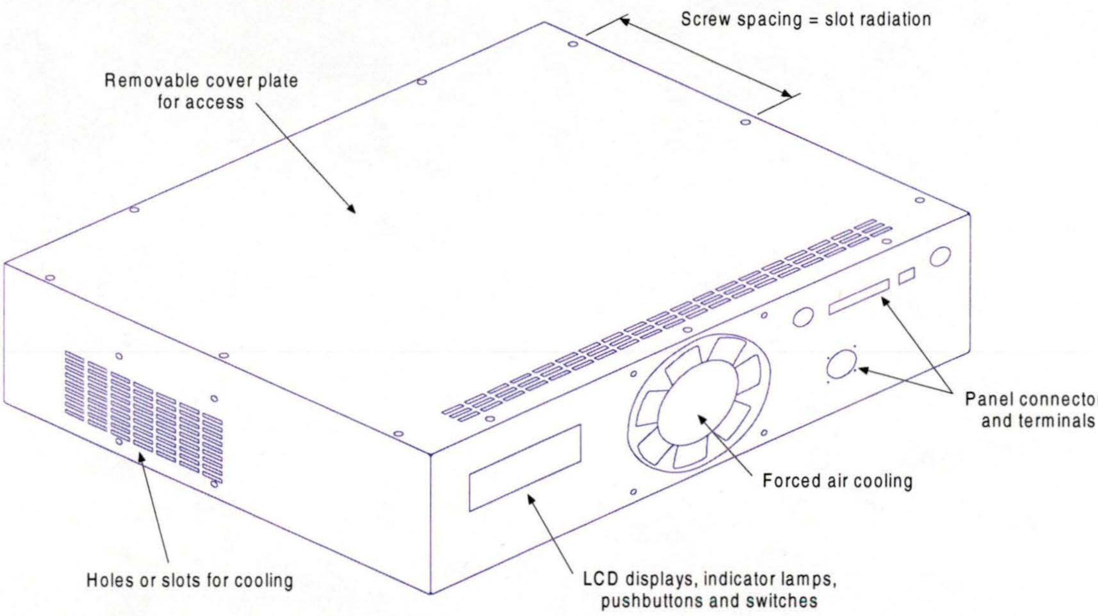



**Figure 4.3.1 - Enclosure Apertures**

The critical factor with apertures is their maximum dimension with a good rule of thumb being to keep maximum aperture dimensions (and length of uninterrupted seams) to less than one tenth of the wavelength of the frequencies of concern. For example, if a circuit was emitting significant harmonics up to 500MHz as a result of the rise time of a clock signal, then maximum aperture dimensions should be kept below 60mm. Alternatively, for immunity to radiated fields at 1GHz (the highest frequency specified in the commercial standards), aperture dimensions should ideally be kept to less than 30mm. In general, aperture size should be minimised and multiple small holes or "expanded metal" grills used in place of single large apertures for ventilation.

The author has actually witnessed a case where a piece of equipment suffering from severe radiated RF susceptibility was made completely immune by dividing an LCD display aperture in half with a fine piece of wire that was virtually invisible.

Transparent, conductive materials are available for viewing apertures but these tend to be expensive, difficult to apply and have a limited shielding effectiveness.

### *4.3.1 Aperture Orientation*

If slots are required in a metal enclosure (eg. for ventilation) then a design choice on the orientation of those slots can have an effect on the EMC of the product. Consider Figure 4.3.2.

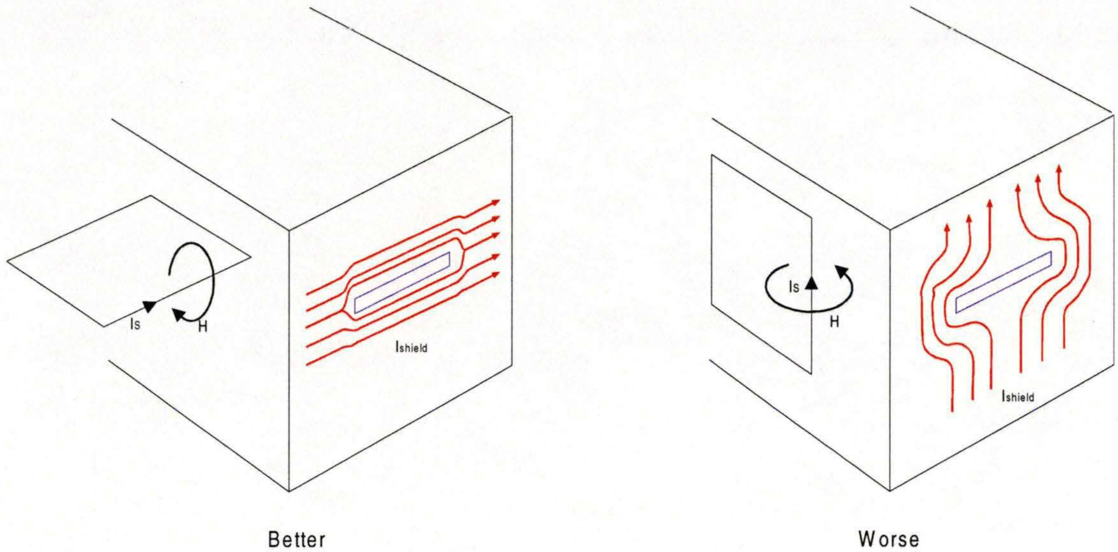



**Figure 4.3.2 - Slot Orientation and Enclosure Shield Currents**

Current flowing in a loop inside an enclosure induces current in the enclosure in the same plane. Theory shows that discontinuities in the shield current gives rise to a field coupling path through the shield and thus interruption of the shield current should be minimised. As illustrated, a long aperture has more effect on currents flowing at right angles to it than on parallel current flow (this is related to slot antenna theory at higher frequencies). In the case where the orientation plane of the current loops is defined (eg. on a PCB) then alignment of slots (and seams) in the same plane as the PCB can give as much as a 10dB improvement in the shielding effectiveness at higher frequencies.

## *4.4 Enclosure design*

The enclosure designer needs a good appreciation of EMC issues, particularly those involved with screening and apertures.

### *4.4.1 Shielded Plastic Enclosures*

If a plastic enclosure is required for ergonomic, functional or cost reasons and EMC is an issue then a range of screening options are still available. Various conductive coatings are available which can be painted or bonded to the interior of a plastic enclosure. These coatings vary in cost and ease of application with a spray-on silver

($0.01\Omega$/sq.) or arc sprayed zinc ($0.2\Omega$/sq.) coating at approximately 12μm thick providing the best shielding performance. Use of such coatings requires the use of mechanical and chemical design rules to ensure good adhesion, uniform thickness and durability. Careful attention needs to be paid to seams and mating surfaces to ensure continuity of the conductive screen.

### *4.4.2 Joints, Seams and Mating Surfaces*

High resistance breaks in a conductive screen act in the same way as apertures and in the case of a long seam this can be catastrophic for EMC. A common fault is to use painted panels with either no metal to metal contact or a masked area for protective earthing continuity at one point only. There are many techniques available to ensure electrical continuity between mating conductive surfaces and a few examples are listed below;

- Use low impedance surface finishes for low contact resistance (eg. Anadine for Aluminium, Zinc or Tin plating for steel or "computer grade" pre plated steel. Chromate passivated steel has a high surface resistivity)
- Use overlapped flange joints (good screening measure for ESD immunity as well)
- Keep the distance between fasteners < $\lambda/10$ for the frequencies of concern
- Use a preset torque driver on fasteners to ensure consistent contact pressure
- Increase the mating surface area by using interlocking geometries
- Use conductive gaskets between mating surfaces (a large variety of different shapes and material types are available)
- Use spring "fingerstocks" on doors and hatches (relatively expensive and requires significant force to close - used on screened room doors)
- Place bonding straps between panels (at least every $\lambda/10$)
- Use conductive tape over seams (usually a diagnostic or temporary measure)

## ***4.5 Cable selection***

Connecting cables are major conduit for RF interference to enter or leave a piece of equipment. Cable performance and application is a stand-alone field of EMC expertise and is usually the domain of the system designer. However, the choice of cables (and the method of termination at the equipment enclosure) has a great impact on EMC design decisions for the apparatus itself. For example, the choice not to use screened cable on a communications port in order to save cost may require extensive measures to be taken on the communication port circuitry to reduce emissions and increase immunity.

*4.5.1 Shielded or Unshielded?*

The answer to this question (as with most EMC questions) is "It all depends". Generally shielded cables are better than equivalent unshielded ones **provided that the shield is continuous and maintained through terminations and connections.** If this proviso is not met then shielded cables can lead to more problems than they solve.

A summary of the EMC effectiveness of different types of cables for driving unbalanced loads is shown in Figure 4.5.1[16]

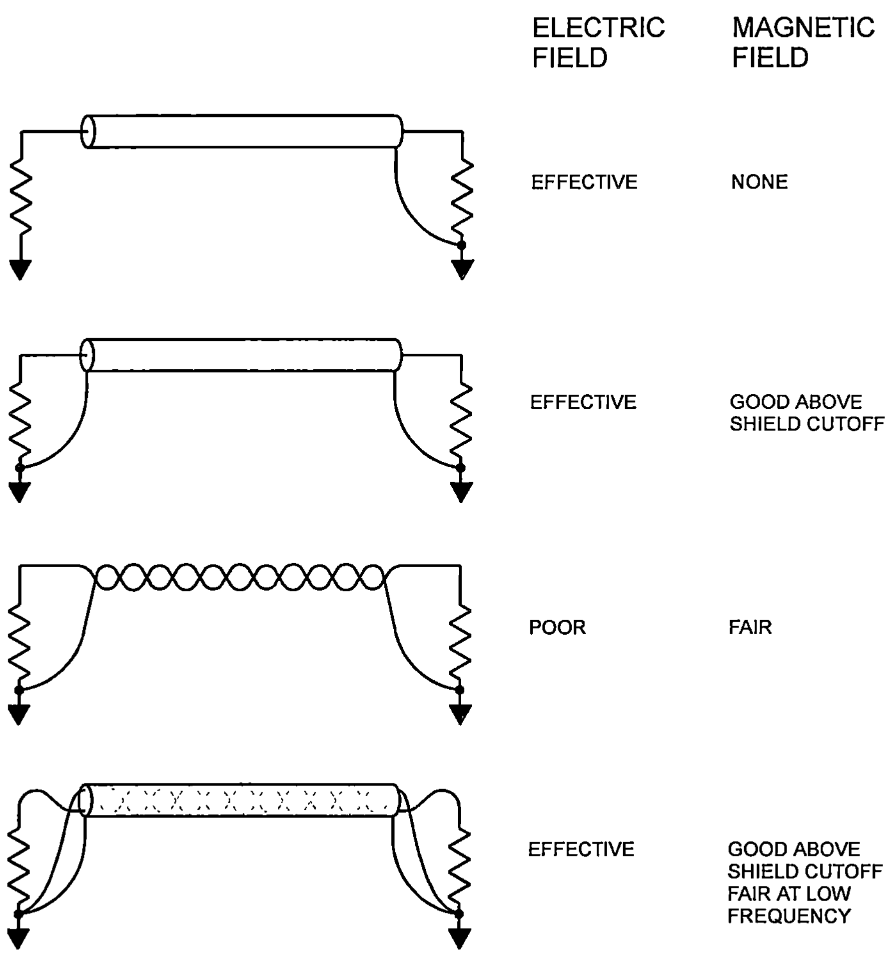



**Figure 4.5.1 - Summary of the EMC effectiveness of cables for E and H fields**

- A shielded cable with a single point ground effectively shields electric fields but not magnetic ones.
- A shielded cable grounded at both ends shields electric fields at all frequencies and magnetic fields that are well above the shield cutoff frequency (the shield cutoff frequency is typically 100Hz to a few kHz depending on the screen braid density).
- A twisted pair provides some protection against low frequency magnetic fields but little protection against electric fields. Good for reducing lower frequency interference particularly in high current circuits (a good way of reducing the

overall loop area). The effectiveness of this technique depends on having enough twists per wavelength (typically 100 - 1000 twists per wavelength gives a good performance)

- A twisted pair can be shielded (with the shield grounded at both ends) to provide electric field rejection and magnetic field rejection which extends down to low frequencies. While apparently the optimum, this configuration has too much variation in characteristic impedance along its length to be useful for high frequency transmission.

Although the above summary would suggest that a cable with its shield grounded at both ends has EMC advantages in all cases, when considering the "ground map" of the entire system this arrangement may actually create a large ground loop which may in fact introduce emission and susceptibility and even operational problems. In summary, each application needs to be assessed with the whole system in mind and an appropriate cable topology selected according to the particular function to be performed and the electromagnetic environment to which it will be exposed.

### *4.5.2 Ribbon Cables*

Figure 4.5.2 below shows a comparison of the emission levels from ribbon cables with different configurations of ground returns[17]. By ensuring that there is a ground return conductor adjacent to every signal conductor an emission level reduction of up to 14dB can be achieved. The fundamental principle involved here is ground impedance minimisation by reducing the enclosed loop area of the signal and ground return circuits. By reducing these loop areas, both the emission and immunity characteristics of the cable are improved. This can be extended to cable routing close to a ground plane or chassis enclosure ground but this is usually more difficult to control.

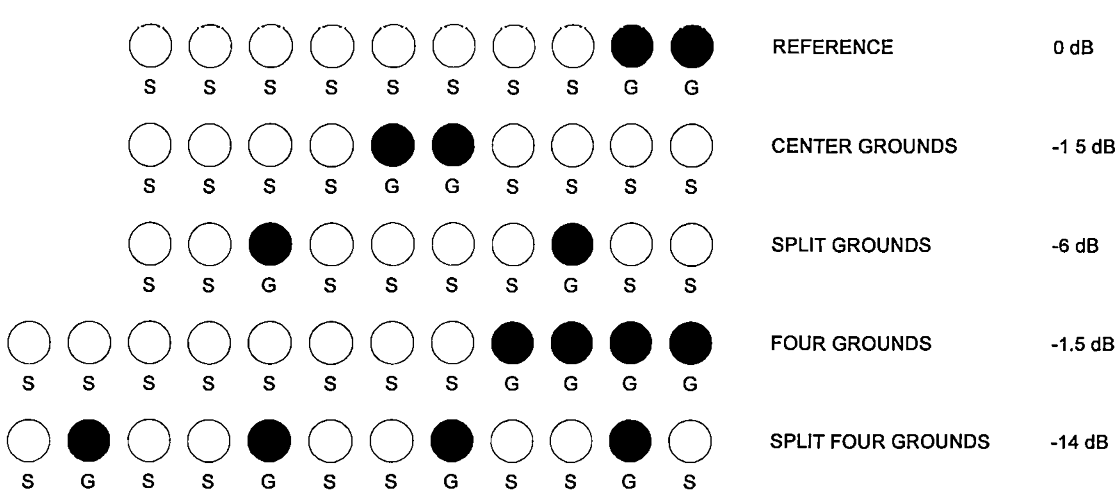



**Figure 4.5.2 - Comparison of the effects of ribbon cable ground configuration**

*4.6 Cable termination*

The effectiveness of a shielded cable can be severely compromised if it is incorrectly terminated at the enclosure or to an RF reference ground. A common "bad" practice is to terminate a cable screen via a short "pigtail" at the enclosure penetration point. The inductance of such a pigtail introduces a significant impedance at RF which in turn allows noise to couple onto the inner conductors (or conversely signal voltages to couple onto the screen).

Correct termination of a shielded cable involves a 360° bond between the cable and the backshell such that an uninterrupted screen is maintained around the signal conductor(s) at the point of penetration of the enclosure as shown in Figure 4.6.1.

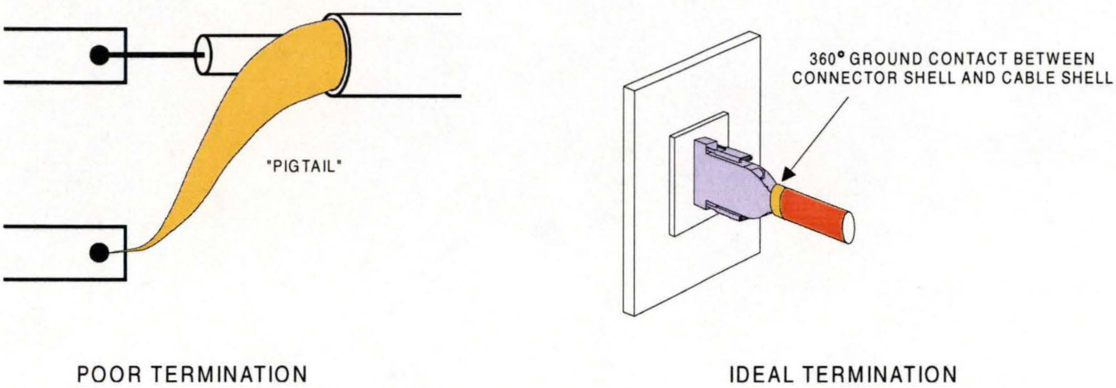



**Figure 4.6.1 - Coaxial cable termination**

*4.7 Filters*

Filtering is often required on unscreened conductors entering or leaving an enclosure (eg. power or load cables) in order to achieve EMC. In addition, some form of filtering is often the first technique out of the EMC "bag of tricks" to be retro-fitted when emission problems are encountered.

When filtering is considered for EMC the aim is usually to introduce a low pass filter with a pass band that will not impede the intended function of the "signals" on the cables yet will sufficiently attenuate the interference conducted via the cable. An important distinction to make when considering filtering is the difference between common mode currents (usually interference) and differential mode currents (usually wanted power or signals).

Differential mode currents are those that flow in one direction on one conductor and in the reverse direction on a return conductor and these are usually equal to the power or signal currents. Provided the overall loop area formed by the forward and return conductors is minimised, the electromagnetic fields created by differential mode currents tend to cancel each other are not usually the main cause of emission problems. Common mode currents flow equally down all conductors in a cable and return via the grounding network. As the loop for the ground return can often be large and relatively uncontrolled, very small common mode currents can cause significant emission problems.

Low pass filtering for EMC can involve RC filtering on low power signal paths or, more commonly, combinations of inductors and capacitors arranged according to the real world input and output impedances on either side of the filter. Depending on the source and magnitude of the interference a capacitor or inductor alone may be adequate. Figure 4.7.1 illustrates some possible filter configurations and the impedance situations for which they are suited. One of the biggest problems encountered is the resonances that are inherent in such reactive filters, particularly those resulting from parasitic capacitance in real world inductors and parasitic inductance in capacitors and their connection leads.

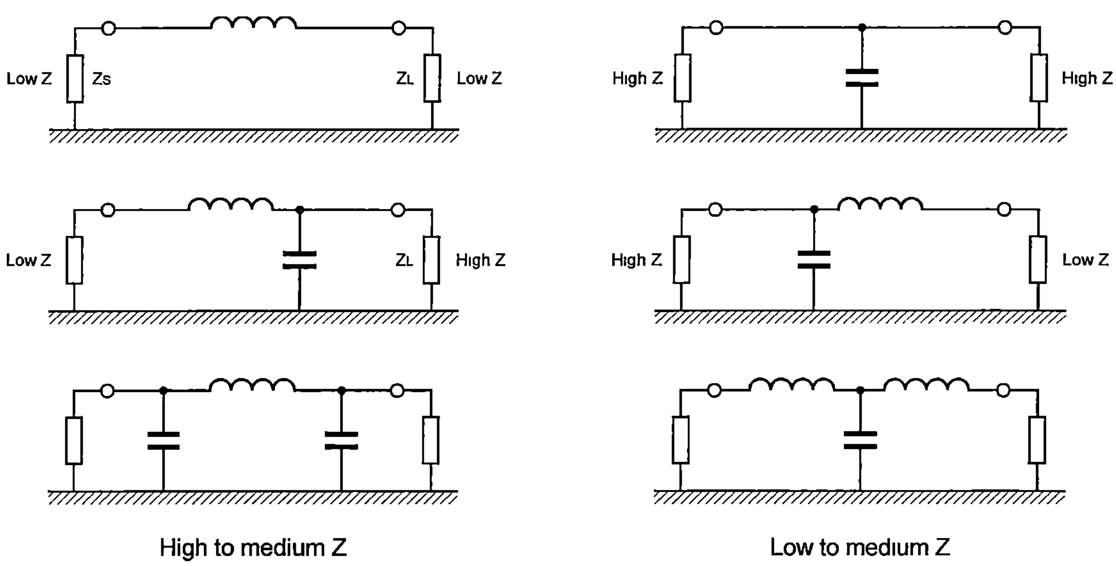



**Figure 4.7.1 - Filter Topologies for Different Impedance Situations**

### *4.7.1 EMC Filter Components*

Some EMC filtering components are listed below along with a non-rigorous description of their function and important features;

- **Ferrites:** Ferrite cores are placed around cables (or a number of turns of a cable is placed through a ferrite toroid) to introduce a common mode "inductive" impedance on the conductors in the cable. The materials used for such ferrites are designed to be lossy at high frequencies and thus they absorb the interference energy and minimise reflections on the cable. A common application of this technique can be observed on the video cables for many computer monitors where a cylindrical ferrite is moulded onto the cable.

- **Capacitors:** Capacitors used for EMC filtering generally require good RF performance. Ceramic capacitors are usually considered the best with surface mount chip capacitors offering the lowest self inductance due to connection lead length. Plastic film capacitors are often adequate and lossy dielectrics can sometimes be an advantage.

- **Inductors**: Whilst inductance is proportional to the square of the turns, the parasitic interwinding capacitance of an inductor also increases with turns. In order to increase the inductance per turn (and keep physical size in realistic proportions) most inductors used in EMC filtering are wound on a high permeability core. The frequency response of such core materials needs to be selected to suit the individual application and the associated problem interference frequencies.

- **Three Terminal Capacitors:** These are capacitors with a special physical termination which limits the parasitic inductance of the connection lead. Essentially these have series input and output signal lead connections These leads connect internally on one "plate" of the capacitor thus eliminating the "T" connection lead length that exists when a two terminal capacitor is connected to a signal line. The earth terminal of such devices should connect directly to the low impedance ground system

- **Feedthrough Capacitors:** This type of device is used to introduce a capacitance between a signal (or power) conductor and an enclosure shield at the point of penetration. These are essentially coaxial capacitors with a suitable dielectric between the inner (signal conductor) and outer (case). The earth connection to the shielded enclosure is a 360° termination formed by mounting the threaded body of the component through a hole in the shield. Such components offer a virtually zero impedance connection to shield and are effective into the GHz frequency range.

- **Feedthrough Filters:** By adding ferrite around the signal conductor in a feed through capacitor, inductive impedance is added and an effective high frequency "π" filter can be produced. These are available as "off the shelf" components.

- **Filtered Connectors:** Multi-pin connectors are available which incorporate ceramic sleeves over each pin with external metallisation on the ceramic sleeve connected to the connector shell. This forms a capacitor at each pin and can be an effective technique for filtering on multi-pin communication ports.

### *4.7.2 Mains Filters*

A range of EMC filters for AC mains connections are commercially available as "off the shelf" units and these offer varying features and levels of performance. A schematic of a "fully featured" mains filter is shown in Figure 4.7.2 and the essential and optional features of this topology are discussed below. There are some special requirements and limitations on mains EMC filtering and these are also outlined in the discussion of the filter topology that follows;

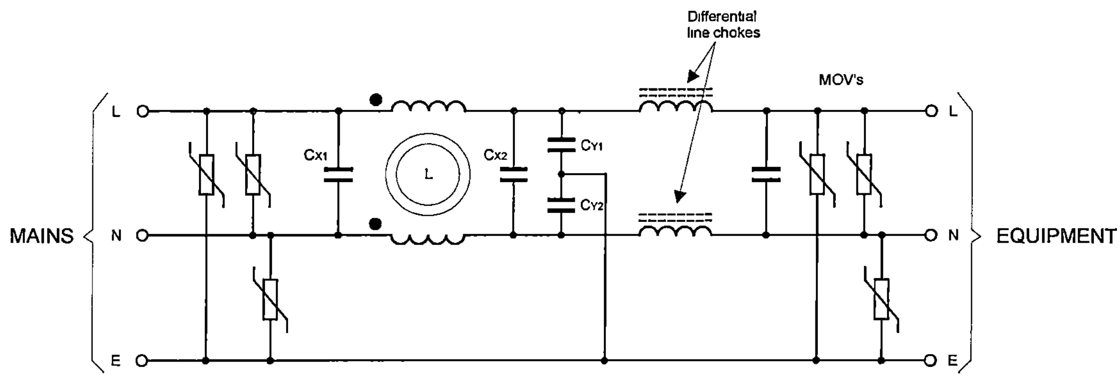



**Figure 4.7.2 - Fully Featured Mains EMC Filter**

The essential elements of a mains EMC filter are the common mode choke "L", the "Y-grade" capacitors CY1 and CY2 and the "X-grade" capacitors CX1 and CX2. These elements generally provide excellent common mode filtering and some nominal differential mode filtering. The common mode choke consists of two identical windings on a high permeability ferrite toroidal core which are wound such that there is flux cancellation for differential mode currents. This winding configuration produces a large common mode inductance (typically 1 - 10mH) on a relatively small core which does not suffer from saturation due to the large differential power current. The only differential mode inductance offered by such a component is the leakage inductance of the windings and this is typically only a few microhenries and has to be limited to avoid core saturation.

The Y-grade capacitors are fire and safety rated for connection between the hazardous mains voltage lines and protective earth and these are the key components in reducing conducted emissions. Indeed if there were no limit on the size of these capacitors mains filtering would be relatively easy. Unfortunately (from an EMC perspective) there is a limit to the amount of earth leakage current that is permitted for mains connected equipment. This is safety related and, depending on the equipment, usually limits the size of the Y-grade capacitors to a few nanofarads (4n7 typically). Thus, the designer is usually constrained to using the maximum allowable capacitance to earth and varying the size of the common mode choke.

The effectiveness of this filter topology depends on the relative source impedance of the noise from the equipment and the load presented on the mains side (50Ω/50μH Line Impedance Stabilisation Network for testing in accordance with CISPR standards) but generally the configuration shown is the most appropriate. The X-grade capacitors CX1 and CX2 (fire and surge rated for line to neutral connection) are generally two orders of magnitude larger than the Y-grade components (0.47μF typically) and serve to attenuate differential mode noise. Either of these may be omitted depending on the performance required although CX2 is nearly always included to provide a relatively low impedance RF path between line and neutral on the equipment side.

The performance of such filters is best investigated using simulation software such as Microsim's P-SPICE but accurate performance can only be modelled if component parasitics are included and the source and load impedances are estimated. Also, the cabling connection configuration and physical earthing arrangement for such filters is as important as the theoretical filter performance with incorrect application often severely reducing or nullifying the effectiveness of a particular filter topology.

Extensions to the performance of the basic filter can be achieved by adding discrete inductances in the line and neutral conductors to improve differential mode filtering (in conjunction with extra Line - Neutral capacitance). These inductors must be rated to avoid core saturation at the AC current peak (often three times the RMS current for non linear current draw) and hence are much larger for a given inductance than a common mode choke.

Transient suppression devices such as Metal Oxide Varistors (MOVs) can be added as shown to provide primary transient protection for all modes on the line and equipment side of the filter thus giving effective shunt surge protection. The author could “wax lyrical” about topologies and design techniques suitable for effective transient surge **filtering** but the important point to make is that adding transient suppressors to an EMC filter topology does not a transient surge filter make. This is due to the fact that the frequencies and current levels involved in transient surges place different design requirements on filters sections suitable for slowing down rise times and reducing “let through” voltages.

### *4.8 Suppressors*

Transient suppressors for EMC are often seen as an extension of filtering and many of the same design and application rules apply. The use of transient suppressors or divertors is essential when circuits are to be made immune to the more severe levels of transient electromagnetic phenomena such as lightning transients, Electrical Fast Transient (EFT) bursts and Electrostatic Discharge (ESD). Some of the transient suppression devices available are outlined below;

- MOVs (Metal Oxide Varistors): These devices are non-linear, voltage dependent resistors with symmetrical voltage-current characteristics. The resistance presented by a varistor decreases with increasing voltage with a high degree of non-linearity. This non-linearity is such that the varistor presents a very high impedance up to a particular voltage at which point a "knee" in the characteristic is reached and any further rise in voltage is virtually short circuited. The fast response time (< 25nS) and potential for high energy absorption make these devices ideal for use as transient overvoltage shunt diverters. The principle of operation of a MOV is illustrated in Figure 4.8.1. Sintering zinc oxide, along with other metal oxide additives, under set conditions results in a ceramic material in which highly conductive zinc oxide grains form within a highly resistive intergranular medium consisting of other oxides[18]. At the junction where the zinc oxide grains contact one another, "micro-varistors" are formed which have V-I characteristics similar to symmetrical zener diodes. A Metal Oxide Varistor is thus formed by the multiple series-parallel connections of these micro-varistors within a piece of the ceramic material. The thickness of the material sets the number of series connections and hence the conduction or "knee" voltage while the cross-sectional area determines the number of parallel current paths and hence the current handling capability. The energy absorbing capability of the MOV is thus determined by the product of these two parameters which is the volume of the piece of ceramic.

## MOV INTERNAL STRUCTURE

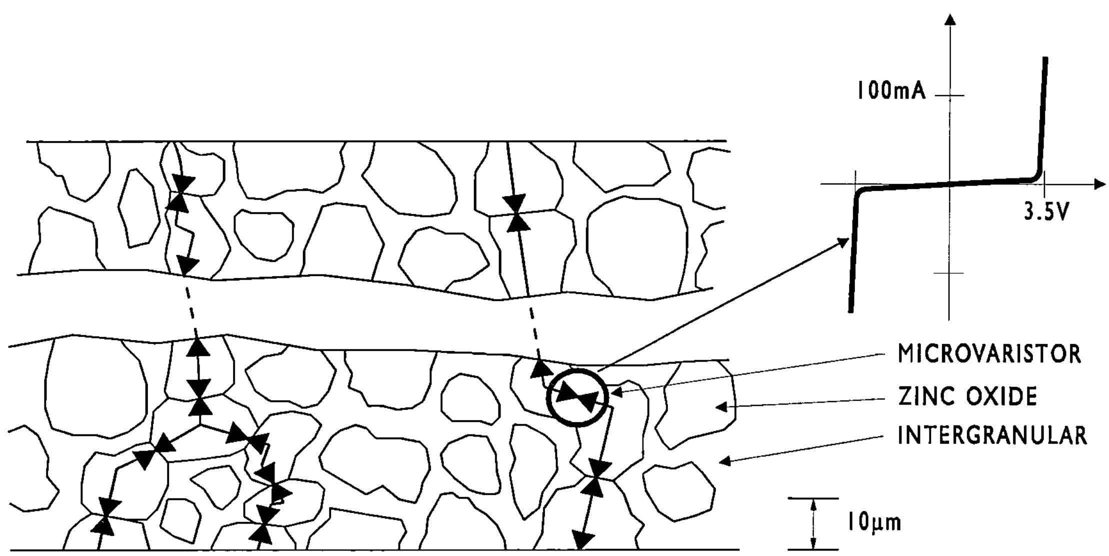



**Figure 4.8.1 - MOV Internal Structure**

- Transient Suppressor Diodes: This family of components are essentially high wattage Zener diodes which are rated for short duration transient currents. These are ideal for protection of sensitive data and signal lines against lower energy level, fast rise time transients.

- Gas Arresters: Some times called GDTs (Gas Discharge Tubes) these devices are essentially a close tolerance spark gap surrounded by an inert gas in order to give a well defined spark over voltage. These devices tend to be "slow" to act in the microsecond time scale but are able to divert large peak transient currents (orders of magnitude larger than can be handled with transient suppressor diodes). GDT's are usually employed as primary, high energy diverters on exposed data and communication lines.

- RC Contact Suppressors: Any spark capable contact should be suppressed using a series resistor-capacitor combination in parallel with the contact to limit the rate of rise of voltage to much less than 1V/µS. Such combinations are available as single components designed to be used with multiple contact arrangements and to suppress arcing noise from electrical motor brushes.

#### *4.8.1 Suppressor Application*

Different types of surge suppressors can be combined with series decoupling components and filters to produce excellent transient protection for any type of electrical circuit. Appropriately designed "Surge Reduction Filters" reduce both the peak magnitude and the rate of rise of the "let through voltage" by orders of magnitude compared to the performance of shunt surge suppressors alone. Due to the extremely fast rise times of many of the transients encountered, layout, lead length and physical position of transient suppression devices are as critical as the device specifications. In general, transient suppression should be situated at or near the point of penetration of a cable to an enclosure and the length of any "T" connections (including lead lengths) to suppressor components should be minimised. If devices are being employed to suppress internal transients at their source, such as suppressing overvoltages due to switching of inductive loads (flywheel diodes on relay coils etc.) or contact suppression, then the devices should be situated as close to the source as possible and the area of the enclosed loop for transient current flow should be minimised.

### *4.9 Choice of Configuration*

Fundamental design decisions on circuit configuration can have a marked effect on EMC and thus EMC needs to be factored into initial design decisions.

#### *4.9.1 Digital Configuration:*

Digital circuits are a prime source of electromagnetic emissions and microprocessor based systems can be extremely susceptible to electromagnetic phenomena if adequate precautions are not taken. Below are some points that should be considered when deciding on a digital design configuration. Unfortunately there are often other design parameters which are in conflict with techniques for good EMC design but where compromises can be made at the initial design stage there are often huge gains made in achieving EMC for the finished product;

- Clock Speed: Use the slowest clock speed possible and limit high frequency clocks to sections of the circuits where they are necessary. For example extending a high frequency clock signal to a section of circuitry where it is divided down may create unnecessary emission problems.

- Rise/Fall Times: Slow down rise/fall times of digital signals as much as possible to limit the magnitude and range of frequencies of harmonics in the resulting frequency spectrum.

- Microprocessor Systems: Minimising the area of circuitry associated with a digital microprocessor system maximises EMC for that circuit (due to reduced enclosed loop areas etc.). Thus single chip microcontrollers are best, followed (in order of EMC preference) by microprocessors with discrete chip peripherals and external logic and multiboard processor designs with a bus backplane which present the greatest EMC problems.

### *4.9.2 Analogue Configuration*

Generally, EMC decisions related to analogue design are directed at improving immunity as, apart from specific RF circuits and Switch Mode Power Supplies, analogue circuits do not usually make a significant contribution to RF emissions. Initial analogue design decisions to improve immunity are usually desirable from a functional point of view also as these are aimed at maximising the signal to noise ratio. Some points to consider when deciding on an analogue design configuration are listed below;

- Bandwidth: Use the lowest bandwidth possible that allows proper functionality. It is always prudent to band limit analogue circuits. (eg. 10's of pF of capacitance across op amp inputs often helps).

- Dynamic Range and Signal Level: Increasing the dynamic range of analogue circuits often gives a greater margin for common mode noise rejection. Thus, high power rail voltages can be an advantage. In addition, using the maximum signal level that is practical provides the greatest signal to interference noise margin.

- Balanced Circuits: Use balanced circuits and differential amplifiers where possible for noise immunity.

- Isolation: Opto-couplers and transformers can be used to isolate particularly sensitive coupling paths. This is often used to avoid large ground loops in a system and is sometimes refereed to as "ungrounding" a circuit.

- Switch Mode Power Supplies: The use of SMPS topologies generally gives the most efficient power supply with the greatest power to volume ratio. However the electromagnetic emission problems accompanying such circuits are significant and these must be weighed up against the advantages gained. The emission measurements and results shown in later chapters are from a multiple stage switch mode power supply product and a great deal of design (and redesign) effort was expended in achieving compliance with the appropriate emission limits.

### *4.9.3 Circuit Partitioning:*

When considering EMC at the initial configuration stage, the identification of EMC critical circuits is important. Such circuits may include radiating circuits such as high speed logic and video circuitry, or sensitive low level analogue and microprocessor based circuitry. It is then possible to partition such circuitry in to sections to which appropriate shielding, filtering and grounding techniques can be applied. Such partitioning is important in establishing a "ground map" for a system as discussed earlier.

## ***4.10 PCB layout***

Many problems encountered with EMC can be traced back to the PCB layout. The flip-side of this is that if attention is paid to EMC issues as a PCB is being layed out, many potential EMC problems are nipped in the bud and the path to product compliance is a relatively easy one. One hazard with automated and semi-automated

PCB routing software is that EMC issues are not factored into the algorithms and track connections and, in particular, ground networks are connected on a nodal basis with no regard to dimensional aspects which are significant at higher frequencies.

One important criterion effecting EMC performance of a PCB layout (or indeed of a discrete wiring layout) is the enclosed loop area of high frequency and high di/dt circuits. The entire path (including ground return) for high frequency current needs to be considered and the enclosed area of the radiating loop minimised. This can be achieved by appropriate component placement, short and direct track connections, use of localised high frequency or decoupling capacitors and/or by utilising a low impedance ground system as discussed below. The theory of reciprocity suggests that the efficiency of a radiating antenna is directly related to its efficiency as a receiver. Thus by minimising loop areas, not only is the potential emission profile reduced but, in general, the immunity to external electromagnetic phenomena is increased.

### *4.10.1 Ground Nets on PCBs*

Low impedance ground connections (preferably viewed as low impedance return signal paths) is possibly **the** most important EMC aspect of PCB layout. Design rules for achieving low impedance ground returns, in order of increasing effectiveness, are outlined below;

- Minimise Loop Area: When placing a discrete ground track, the total enclosed loop area formed by the signal path(s) and the ground return should be minimised in order to minimise the inductive impedance. This generally means routing the ground return track along side or directly underneath the signal path track.

- Minimise Track Impedance: This applies equally to signal and ground return traces. Whilst increasing the width of a track reduces its self inductance, this is only a secondary effect compared with reducing the length of the track. Thus, track lengths (signal and ground returns) should be minimised. Time spent determining optimum component placement and orientation for minimal connection lengths usually pays dividends in the long run.

- Use Ground Grids: An interconnected grid of ground tracks (typically running horizontally and vertically between ICs on a digital PCB) presents a further reduction in ground impedance. In such a grid, the individual track impedances are effectively parallelled as the separation distances are great enough to negate any mutual inductance effects.

- Use Ground Area Fills: This is the best alternative for single and double sided PCBs. In addition to laying out a low impedance ground net, all unused PCB area (including a 1cm margin around the extreme signal tracks) should be filled with a copper plane or fine grid mesh (eg 12mil tracks on a 25mil grid : 1mil = one thousandth of an inch). It is **imperative** that all of these copper fill areas are connected to the ground grid and any isolated “floating” islands are removed as floating areas of copper fill can act as “re-radiating” antennas or coupling paths and create serious problems. It is also important that critical tracks have a defined return path, preferably via an uninterrupted section of ground plane immediately below (and, if possible, on either side of) the track for its entire length.

- Use Power and Ground Plane: The best arrangement is to use dedicated power and ground planes on a multilayed PCB (4 layers or more). Here the power and ground nets are presented as solid copper planes with short connections to the signal layers using vias. The best EMI control is achieved by ensuring that there is a ground plane used for return currents adjacent to every signal layer in a multilayered structure.

## *4.11 Software design*

Appropriate design features in software code (particularly that used for embedded control) can significantly enhance the EMC of a system.

### *4.11.1 Programming Techniques for Electromagnetic Immunity:*

Often called "defensive programming" these techniques are good design practice and can sometimes be used to mask hardware inadequacies in embedded control. There is however, an inherent penalty in execution speed;

- Use a "watchdog timer" to automatically reset "locked up" systems.
- Check the validity of inputs and use multiple reverifications before acting.
- Take "rolling averages" of analogue inputs.
- Employ software deglitching and debouncing of digital inputs.
- Don't rely on "latched" settings but refresh ports and registers as often as possible.
- Avoid the use of latched output states (always reverify and refresh).
- Protect and refresh volatile RAM using checksums on tables of data.
- Provide returns from unused interrupts and unused program memory.

### *4.11.2 Programming Techniques for Electromagnetic Emissions:*

It is possible (although not always practical) to change the emissions profile from a microprocessor based system by altering the way the software is run. If embedded control is of a supervisory or reporting nature then running the software in short bursts with "sleep" periods in between will produce a lower overall noise level than a continuously active system (particularly for quasi-peak and average measurements).

Another emissions lowering technique that is emerging is the use of firmware for Spread Spectrum Clock Generation (SSCG). This technique uses a pseudo random generator to jitter the frequency or phase of the clock signal and thus spread the resulting frequency spectrum. Reduction in the peak amplitude detected by a receiver (using a CISPR bandwidth of 120kHz) can be reduced by up to 10dB using this technique.

### *4.12 Computer Aided Design for EMC*

There are a number of useful tools available to designers to assist in achieving EMC but all are limited in their usefulness.

Circuit simulation packages such as Microsim's P-SPICE are very useful for characterising the performance of various filter and suppressor topologies and allow circuit and component parasitics to be taken into account. However the usefulness of such packages for modelling the complete emissions and immunity profiles of circuits of medium to high complexity is limited due to the difficulty in including all the relevant parameters necessary for accurate modelling.

Packages for predicting shielding effectiveness use finite element analysis techniques and produce excellent results. These packages tend to be expensive and often require huge memory and processing resources for anything other than simplistic systems. Such systems are often employed in military EMC applications where time and cost is often no object but economic commercial versions with suitable user interfaces are yet to emerge.

The other main class of EMC CAD tool is that aimed at predicting the emissions and immunity profiles of relatively simple PCB and cable layouts as well as the EMC effectiveness of individual components and materials. One such suite of software is offered at relatively low cost from EMF-EMI Control Inc. (Don White Consultants) in the USA (http://www.summit.net/emf). A menu of the prediction and analysis tools in this suite is shown in Figure 4.12.1. This type of software is useful for instructive purposes and for illustrating the effects of various EMC design techniques but, in the author's view, is not suitable for modelling anything other than simplistic or general arrangements.

The "all encompassing" modelling program capable of predicting the EMC performance of complete "real world" products or sub assemblies does not, and probably will never, exist in a commercially viable form. Even the extensive (and expensive) military based models produced are aimed at very specific applications and require enormous amounts of parametric data in order to produce accurate results.

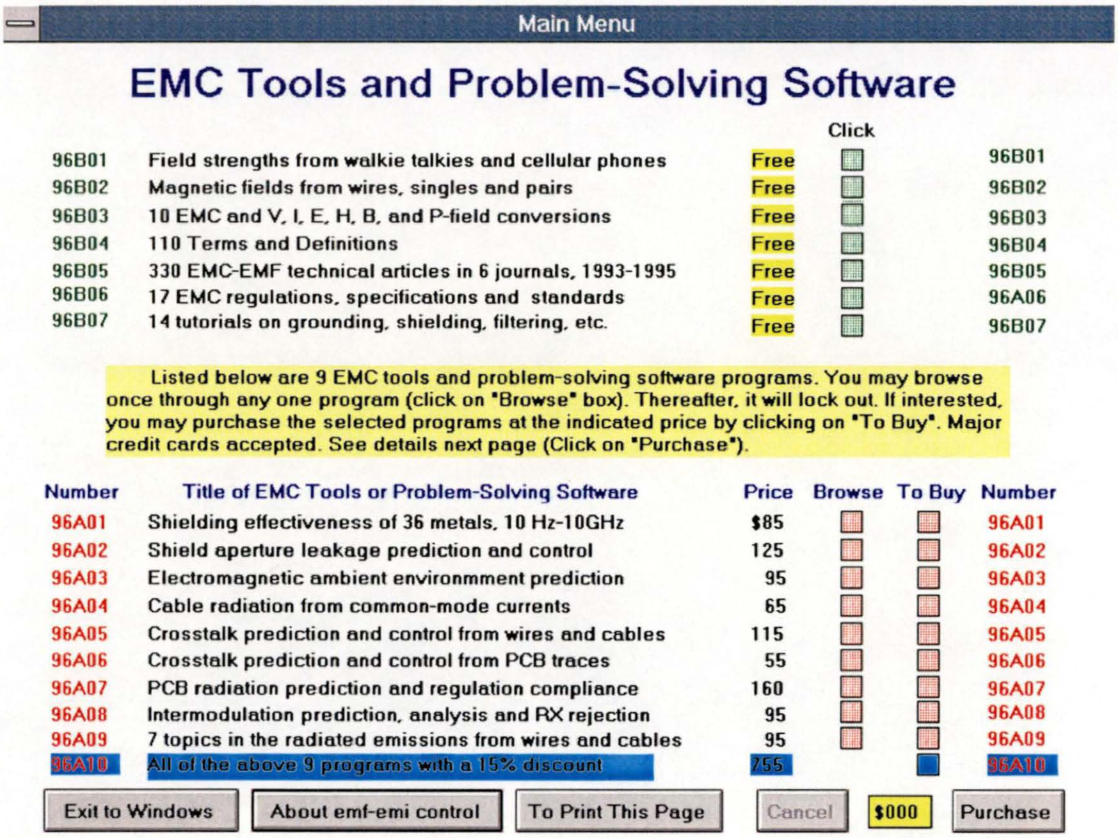



**Figure 4.12.1 - EMC Software Available from EMF-EMI Control Inc.**

# 5. EMC Measurement

## *5.1 Fundamentals*

Working in the field of EMC requires an understanding of a number of fundamental principles of Electrical Engineering. While no attempt is made to cover these principles in this work, it is useful to introduce some of these fundamentals in order to highlight areas of theory that may require revision when embarking into the world of EMC for the first time.

### *5.1.1 Measurement in dB*

Most EMC level measurements are related to a decibel or dB scale. It is thus important to have an understanding of the fundamentals and advantages of the dB scale of measurement for voltages and power. It is also important to have a "good feeling" for the relative size of quantities measured on a dB scale (eg. that halving a voltage level corresponds to a 6dB drop). It is also essential to have a grasp of common absolute units of measure such as dBμV and dBm and common conversion factors

eg. for a 50Ω system;

$0dB\mu V = -107dBm = 1\mu V$

$x\ dBm = (x + 107)\ dB\mu V$

and some typical absolute voltage levels;

$50dB\mu V = 0.3162mV$

$60dB\mu V = 1mV$

$70dB\mu V = 3.162mV$

$80dB\mu V = 10mV$

$120dB\mu V = 1V$

### *5.1.2 Electromagnetic Theory*

A working knowledge of wave properties and transmission line theory is essential for understanding electromagnetic phenomena, measurements and design rules. Background theory includes Maxwell's equations and the fundamentals of signals, linear and non-linear systems. Some key areas include;

- Balanced and unbalanced systems
- Near-Far field transition region at $\lambda/2\pi$ beyond which $E/H = 120\pi = 377\Omega$
- The meaning and effect of VSWR

- Noise mechanisms
- Modulation techniques
- Antenna Theory

### *5.1.3 Filters*

A thorough knowledge of passive filter theory and a practical understanding of passive components is invaluable in EMC work. In particular, the fundamentals of inductors and capacitors and their application in L-C low pass filters should be well understood. Also the factors effecting mutual inductance and the theory of skin effect at high frequencies is useful knowledge.

### *5.1.4 Time - Frequency Domain Transformations*

Much of the skill in predicting and fixing electromagnetic emission problems is related to a basic understanding of the relationship between signals in the time domain and how they appear in the frequency domain. This encompasses a knowledge of periodic and pulse signal spectrums gained from Fourier analysis.

## *5.2 EMI Receivers - Spectrum Analysers*

While specialised, tunable electromagnetic interference receivers are available, the most common instrument used is the spectrum analyser. Most spectrum analysers use the superheterodyne receiver principle where the input signal is combined with a local oscillator in the mixer stage and the combined signal is suitably filtered and amplified in the IF (Intermediate Frequency) stage before being fed to a detector. A superhet, swept tuned analyser, uses a sweep generator to sweep the local oscillator frequency in synchronism with the display beam sweep. This technique allows the filtering and amplification to take place at a fixed, relatively low, intermediate frequency (IF) before the signal is fed to an envelope detector and then via a video filter to the display. Generally some form of signal processing is added to this analogue system to provide peak hold and storage display facilities.

Swept tuned analysers produce the same result as would be obtained if a tracking bandpass filter were applied to the input signal and swept across the frequency range. The display output shows the output of the envelope detector at each frequency in the swept range.

The mixer has to cope with continuous input over the entire specified frequency range of the analyser and thus basic spectrum analysers are susceptible to overload and have limited sensitivity and dynamic range. When coupled with a preselector incorporating preamplification, input protection and a swept tuned filter locked to the local oscillator sweep generator, exceptional sensitivity, dynamic range and noise performance can be attained. Such preselectors often cost as much as a basic spectrum analyser and thus these are generally only used for certified compliance tests. Provided that the user is aware of (and takes precautions against) its limitations and susceptibilities, a basic spectrum analyser is usually more than adequate for making pre-compliance EMI measurements.

The main points to bear in mind when using a spectrum analyser are;

- The input mixer diode is susceptible to damage from continuous overloads and precautions should be taken to protect the input from such overloads. The use of transient limiters is advised where appropriate, as is the use of front end attenuators when investigating unknown signal spectra.

- The wide bandwidth of the input stage generally results in a poor noise figure which may mean that, when the attenuations due to transducers and cables are taken into account, signal levels around the lowest emission limit specifications may be close to the noise floor.

- Broadband signals may overload the mixer and drive it into non-linearity even though the signal levels within the measurement bandwidth at any frequency are within the instrument's dynamic range. This condition, called gain compression, gives an erroneous results and the linearity of the instrument to the application of set attenuation steps should be checked to ensure that gain compression is not occurring. The concept of compression is explained in more detail later.

### *5.2.1 Measurement Bandwidth*

Generally called the Resolution Bandwidth (RBW), this is the bandwidth of the notional bandpass filter whose centre frequency is scanned across the input signal. CISPR specifies the following bandwidths for making EMC emission measurements;

| CISPR FREQUENCY BAND | FREQUENCY RANGE | CISPR MEASUREMENT BANDWIDTH - 6dB (RBW) | BASIS FOR BANDWIDTH SELECTION |
|---|---|---|---|
| A | 9kHz - 150kHz | 200Hz | Navigation Systems |
| B | 150kHz - 30MHz | 9kHz | AM Broadcast |
| C&D | 30MHz - 1GHz | 120kHz | FM Broadcast |

The bandwidths specified are the IF filter bandwidths between the points 6dB down from the pass band plateau and are approximately equal to the impulse bandwidths of the filters. These bandwidths have been selected based on the bandwidths used for the typical communication systems (indicated above) in the different frequency ranges. It is unfortunate that many general purpose spectrum analysers do not include these RBW filter values as standard and these generally have to be requested as an optional extra for EMC measurements.

By using specified, set bandwidths for EMC measurements, the segregation of signal types into broadband and narrowband classifications is relatively simple. If the signal occupies a greater bandwidth than the measurement bandwidth being used in that frequency range then it is classed as broadband in EMC measurement terminology (eg. emissions from digital data transfer). Signals whose bandwidth is within the measurement bandwidth being used are classified as narrowband signals (eg. emissions from oscillator fundamentals and harmonics).

From a more general viewpoint, a broadband signal is continuous across a large part of the spectrum whereas a narrowband signal consists of discrete components falling only at particular frequency positions. As a consequence, a broadband signal is usually measured in units of volts/Hz, while a narrowband signal is not affected by measurement bandwidth. Therefore, the simplest way, in principle, to test for a broadband signal is to measure the amplitude at two different measurement bandwidths. The amplitude of a completely broadband signal will change at the rate of $20\mathrm{Log}_{10}$(bandwidth ratio). This simple procedure usually works quite well. However, a few cautions are in order, because the same pulsed signal will behave as broadband or narrowband depending on whether the pulse repetition frequency (PRF) is less than or more than the resolution bandwidth[19]. This distinction is useful for signal characterisation but the bandwidths to be used for CISPR EMC measurements are set and thus the amplitudes measured are absolute regardless of whether the signal is broadband or narrowband.

### *5.2.2 Display Compression*

As mentioned previously, one of the less desirable scenarios resulting from broadband (and sometimes narrowband) EMI measurements is signal display compression. The usual measurement bandwidth, such as 9kHz or 120 kHz, is significantly less than the possible occupied EMI spectrum width, especially when broadband signals are involved. Broadband signals have a continuous spectrum spanning a large range of frequencies. Hence, the total signal spectrum power can be much greater than the "bandwidth intercepted" display level.

The following "non rigorous" explanation of the problem of compression comes from an application note for the Tektronix 2712 spectrum analyser;

*A 100 kHz measuring bandwidth compared to a 100 MHz spectrum width is a ratio of 1000. Thus the total power input to the spectrum analyser is 60dB greater than that displayed. Such differences can overload, or even destroy, the input circuits. Fortunately, EMI signals having flat spectra covering hundreds of megahertz are extremely rare. Most wideband spectra start at a large amplitude at a lower frequency and progressively get smaller in amplitude at higher frequencies. The time/frequency relationship for pulses is governed by "reciprocal spreading". A wide time pulse results in a narrow spectrum, while a narrow pulse results in a wide spectrum. Thus, a 1 μs wide pulse has a first spectrum zero null at 1 MHz. It takes a very narrow pulse (only 10 ns wide) to move the spectrum null out to 100 MHz. Wider spectra require even narrower pulses. Since the impulse strength of a narrow pulse is twice the pulse area, the pulses have to be of substantial amplitude to damage the spectrum analyser. The narrower the pulse, the greater the required amplitude to maintain the same pulse strength. Nevertheless, signal overload can occur. Knowing whether a signal is narrowband or broadband can be of great help in deciding* *whether mixer overload resulting in signal compression and distortion might be a potential problem.*

### *5.2.3 Types of Detectors for Signal Amplitude*

Three types of signal amplitude detection methods are specified in the CISPR standards;

1. Peak Detection
2. Quasi Peak Detection
3. Average Detection

*Peak Detector*

This is the classic envelope detector normally used for spectrum analyser measurements. This usually consists of a diode feeding a parallel capacitor-resistor combination to achieve a "fast attack - moderate decay" peak response which effectively tracks the envelope of the peaks of the IF signal. The use of such a detector gives the **highest reading of signal amplitude** and enables the **fastest sweep time** to be used. Peak detection is used whenever possible with the "slower" detectors only used if the peak amplitude is beyond the specified limit.

*Quasi-Peak (QP) Detector*

The essential philosophy followed by CISPR is that EMI measures are intended to test for the subjective "annoyance level" of the interference to broadcast reception as judged by a "typical person". A high level of interference that happens infrequently may be less annoying than a lower level of interference that is continuous. This is the basis for the measure known as quasi-peak or QP. The specifications for the QP detector date back to the early days of CISPR when subjective estimates of the "level of annoyance" were made on intermittent interference with AM radio reception. A QP detector is a leaky peak detector with weighted charge and discharge times. The output, intended to be a measure of "the annoyance" caused by the interference, will be less than the peak value depending on the pulse repetition frequency (PRF). The lower the repetition rate, the greater the dB difference between peak and QP. The peak and QP "annoyance factor curves" merge at about a 10kHz PRF even for the 120 kHz measuring bandwidth. Indeed, the peak and QP difference is only a few dB even at a 1 kHz PRF, however, the two results diverge rapidly, reaching over 40 dB at very low EMI pulse rates. Thus, for very low repetition rate pulsed signals, there is a substantial reduction in 'apparent' interference when measured in QP mode, provided the pulse width is narrow enough to appear impulsive. Low PRF but very wide width pulsed signals tend toward a CW (continuous wave) appearance.

Most signals do not need to be measured in QP mode. QP has no advantage for narrowband, CW signals and little effect on broadband signals of more than a 1 kHz repetition rate. Even for low PRF broadband signals, there is no legal requirement to measure with a QP detector. In general though, only by running a test in QP mode can full advantage of the lower legal EMI limits be obtained for low PRF interference. Unfortunately, QP measurements are slow, and reduce the available spectrum analyser dynamic range. It is estimated that the time taken to do a complete QP scan from 150kHz to 30MHz is about 50 minutes (compared with tens of seconds for a complete peak scan). Thus a peak scan is usually done with spot QP measurements made at frequencies where the peak detected signal level is on or above the QP limit to see if the QP level is lower. If the peak level is below the QP (or average) limit then there is no need to test in QP (or average) mode.

There are many opponents to the use of QP detectors. Due to its history and subjectivity of its derivation, many regard the QP detector as out of date and irrelevant. It would seem however that the QP detector is so well established in the basic CISPR standards that it will be specified and used for some time to come.

*Average Detector*

As the name suggest, the average detector measures the average level of a signal. On a spectrum analyser, average detection can be effected using the post detection video filter. By setting the video bandwidth to well below the lowest expected modulation or pulse frequency in the emission signal, an average measurement is obtained. This usually means setting the video bandwidth to its lowest level (typically 1 or 3Hz) and adjusting the span per division and sweep rate to a low enough level to get a "calibrated" result. This results in extremely long scan times over a complete band and average measurements are usually only applied at spot "problem" frequencies.

### *5.2.4 Emission Limits*

It has been found that below 30MHz, conducted emissions along mains and other cables cause the greatest problems (particularly to long, medium and short wave radio communication). Above 30MHz, radiated emissions from equipment and connecting cables dominates. Thus, conducted emission limits are specified up to 30MHz and radiated emission limits apply at higher frequencies.

Only the military specify limits using a peak detector. Commercial standards specify Quasi-Peak and average limits for conducted emissions in CISPR Band B (150kHz - 30MHz) and only QP limits for radiated emissions in CISPR Band C (30MHz - 300MHz) and CISPR Band D (300MHz - 1GHz). For conducted emissions, the average limits are typically 10dB below the QP limits, thus placing a penalty on continuous emissions which will display the same average and QP levels as opposed to pulsed or modulated interference which will register a lower level on an average detector.

A comparison of limits specified in CISPR and FCC standards is shown in Figures 5.1 and 5.2. Currently only existing VDE standards, military standards and some draft ETSI standards specify limits on conducted emissions in CISPR Band A (9kHz - 150kHz) and only ANSI standards extend the radiated emission limits beyond 1GHz for some equipment.

A good approach to take when doing pre-compliance measurements for conducted interference is to use a peak detector and apply the most stringent CISPR Class B average limits.

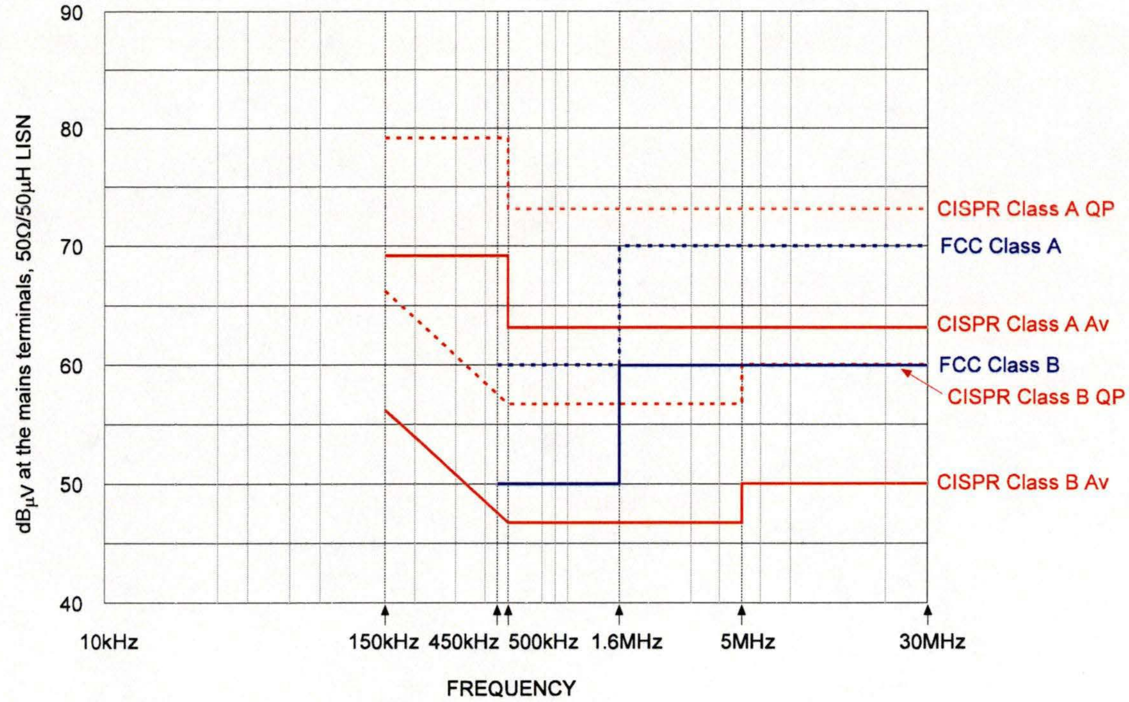



**Figure 5.1 - Conducted emissions limits**

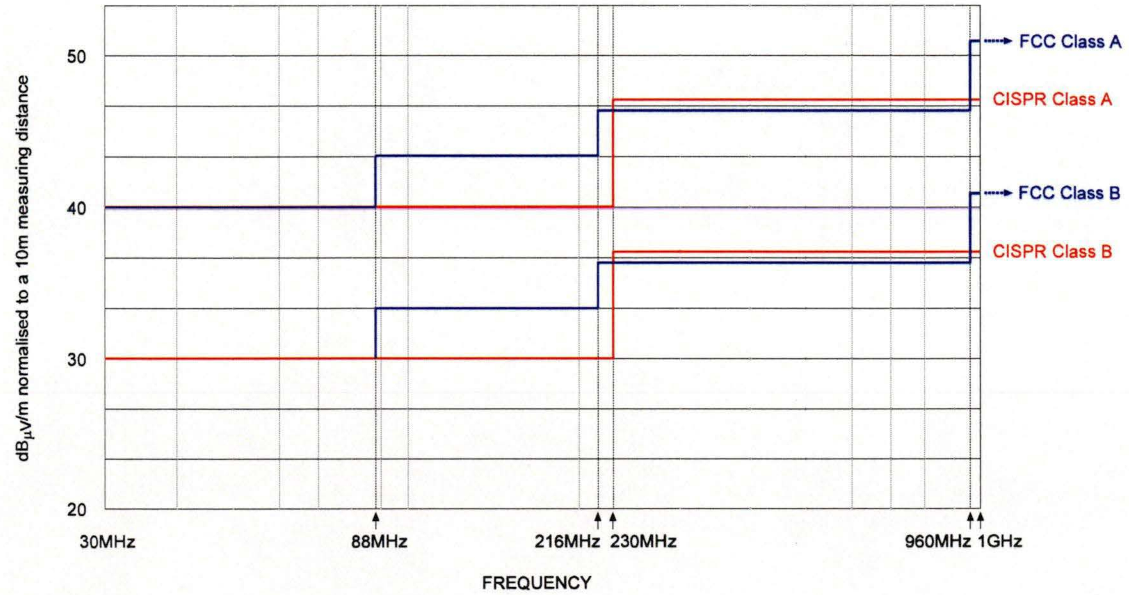



**Figure 5.2 - Radiated emissions limits**

It is always the case for detected signal levels that;

**Peak ≥ Quasi-Peak ≥ Average**

Thus by applying the average limits to the peak detected emissions and complying, a good safety margin is maintained for pre-compliance. If signal levels are on or above the average limit line at various frequencies then the QP and average detectors can be used to investigate if the signal characteristics are such that the levels are reduced with these detectors. The 10dB increase in the QP limit level can then be taken into consideration if the average measurements drop down comfortably below the average limit line. (Note compliance with both QP **and** average limits is required when they are specified).

Similarly, pre-compliance using peak detection with CISPR QP Class B limits for radiated emissions means that any reduction in level when using a QP detector can be used as a safety margin. The QP detector can be used to measure spot problem frequencies to again characterise the type of emission and get a feel for how much reduction can be achieved with this specified detection method.

### *5.3 Transducers*

In addition to a measuring instrument, various transducers are required to make EMC emission measurements in accordance with the standards. The essential transducers for EMC emission measurements are introduced below and these and other EMC transducers are discussed further in Chapter 6;

#### *5.3.1 Line Impedance Stabilisation Network (LISN)*

For the measurement of conducted emissions on power ports (both mains and DC) an artificial network is specified. The purpose of this network is to;

1. Isolate the equipment under test and measuring receiver from any external sources of noise present on the power conductors.

2. AC couple the RF signal to the measuring receiver while rejecting the large, low frequency power supply voltages.

3. Provide a defined impedance at RF across the measuring point.

The most commonly used LISN specification is that provided in CISPR 16 which presents an impedance equivalent to 50Ω in parallel with 50μH across each line to earth in CISPR Band B. The basic schematic for a CISPR 16 LISN network for one line to earth is shown in Figure 5.3. The standard specifies the impedance (with an allowable tolerance of ±20%) that the LISN should present in the measurement frequency bands A&B. This impedance is nominally 50Ω in Band B (150kHz - 30MHz) as specified for mains power port measurements and drops down to nominally 5Ω at the bottom end of Band A (10kHz - 150kHz) for some DC power port measurements.

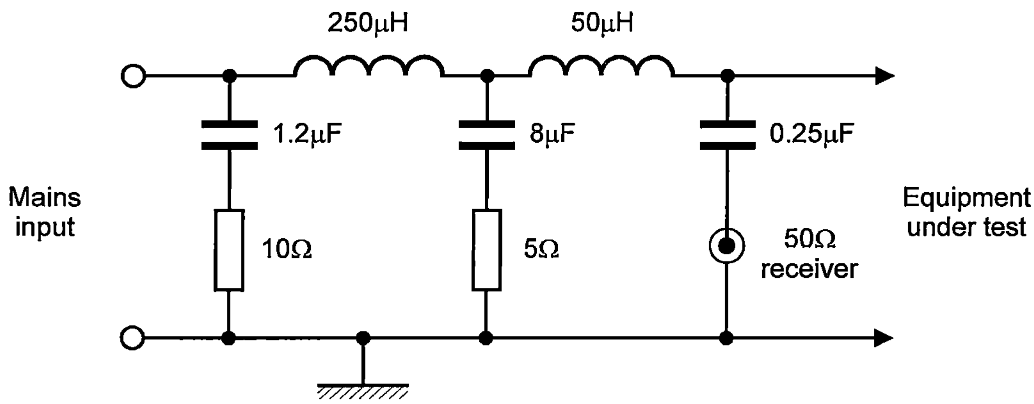



**Figure 5.3 - Schematic of a LISN network for one line with respect to earth**

*5.3.2 Antennas*

Broadband antennas are required for radiated emissions measurements. These antennas act as transducers to convert the electric field strength measured at a specified distance from the equipment under test to a voltage measured across the 50Ω input of the spectrum analyser. Generally one broadband antenna can effectively cover Band C (30MHz - 300MHz) and a second is required for Band D (300MHz - 1GHz). The various physical arrangements of these antennas are outlined in Chapter 6.

These antennas are generally orientated for maximum gain in both horizontal and vertical polarisations. The Antenna Factors for a particular antenna are, in effect, the transducer factor which correlates the voltage measured at the 50Ω input of the spectrum analyser (eg. in $dB_{\mu V}$) to the electric field strength measured at the antenna (eg. in $dB_{\mu V}/m$). There are procedures for measuring these Antenna Factors and initial calibration data is usually supplied by the antenna manufacturer. These factors are usually tabulated in dB at various frequencies across the Band and are simply added to the $dB_{\mu V}$ reading at the receiver to convert to the measured field strength.

In general, for any frequency;

$$E(dB_{\mu V}/m) = V(dB_{\mu V}) + AF(dB) + A(dB)$$

where;

E = electric field strength at the antenna at that frequency

V = the measured voltage at the receiver input at that frequency

AF = the antenna factor at that frequency

A = combined attenuation of the coaxial cable and connectors at that frequency

### *5.4 Open Area Test Site (OATS) for Radiated Emissions*

Radiated emissions measurements can be made in anechoic or partial anechoic screened rooms and such measurements have the advantage of being relatively free from ambient signals and noise. At microwave frequencies and UHF, screened rooms can be made virtually anechoic (ie. non reflecting) by the addition of absorption material on the walls and ceiling. The depth of the absorber on the walls limits the lowest anechoic frequency and it is extremely difficult (and expensive) to build a practical enclosure with sufficient anechoic performance below 100MHz. The measurement uncertainties due to reflections below 100MHz outweigh the advantages of reduced ambients offered by anechoic and semi-anechoic rooms. For this reason, Open Area Test Sites (OATS) or Open Field Test Sites (OFTS) are specified by most regulatory authorities for radiated emissions testing.

When considering in-house test facilities for radiated emission testing, some form of OATS needs to be established. As with most engineering issues, a balance needs to be struck between ideal performance, convenience, practicalities and cost.

The required characteristics of an OATS is specified in detail in CISPR 16 for Europe, Australia and most of the world and by the FCC in ANSI C63.7-1992 for America. The CISPR and ANSI requirements differ in detail but not in substance. Final validity of any test site can only be made by performing site attenuation measurements.

### *5.4.1 Obstruction Free Area*

An obstruction free area surrounding the Equipment Under Test (EUT) and the field strength measuring antenna is required. This area should be free from significant scatterers of electromagnetic fields and should be large enough so that any scatterers outside this area will have little effect on the field strengths measured. This obstruction free area is defined in ANSI and CISPR standards and is illustrated in Figure 6.1. This requirement means that for testing at the smallest practical distance of 3m a minimum obstruction free area of about 6m x 6m is required.

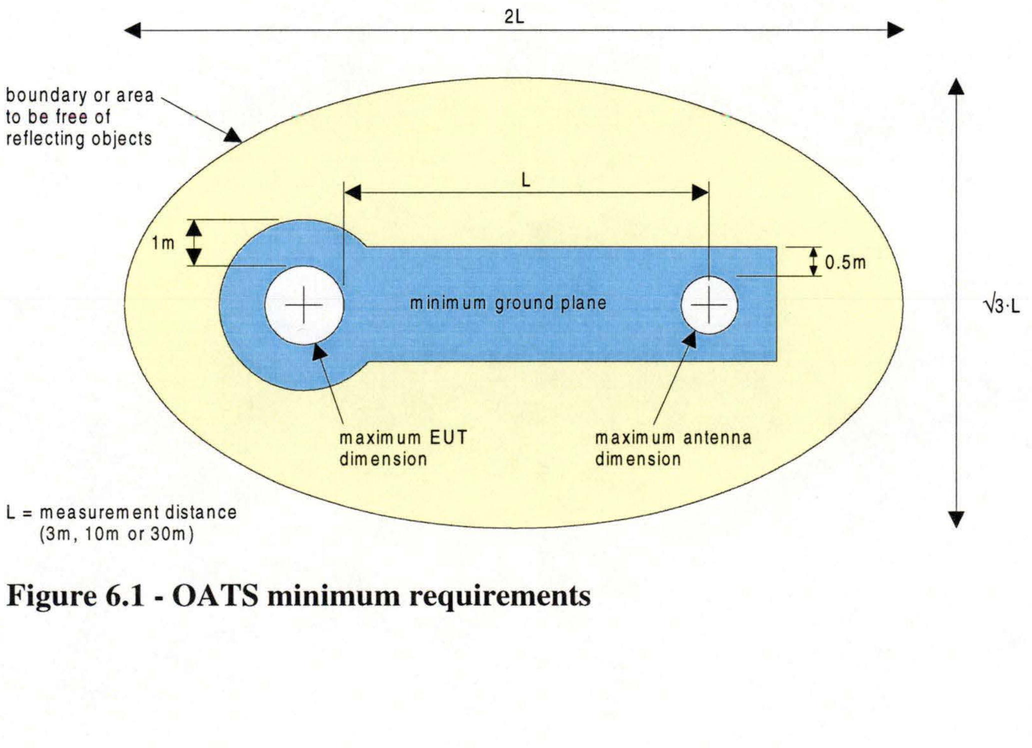



**Figure 6.1 - OATS minimum requirements**

### *5.4.2 Ground Plane Requirements*

In order to achieve repeatable results that do not depend on surface moisture and conductivity a continuous conductive ground plane is required. This should be a continuous sheet, grid or mesh with no discontinuities or gaps greater than $\lambda/10$ for the highest frequency of interest (ie. greater than 3cm at 1GHz or 10cm at 300MHz). As a minimum, the ground plane should extend at least 0.5m beyond than the biggest dimension of the measurement antenna and at least 1m around the equipment under test. This suggests that a ground plane about 3.5m wide and 6m long should be adequate for 3m test distances. ANSI C63.7-1992 has an in depth treatment of "Fresnel Zones" which are areas which contribute to reflections from a ground plane. Analysis shows that the first Fresnel ellipse at 30MHz has a major axis of 9.9m and a minor axis of 9.5m. Thus theoretically the obstruction free area and the ground plane should extend out to be 10m x 10m for 30MHz measurements at 3m. The minimal ground plane size specified above however, has proven to be adequate in practice.

The allowable roughness of the ground plane is determined by the "Rayleigh Criterion" for a specularly smooth surface which is also presented in depth in ANSI C63.7-1992. This result of applying this criterion is that the ground plane can be considered to be specularly smooth if the rms roughness is less than $0.15\lambda$ for the frequencies of interest. (ie. 4.5cm at 1GHz or 150cm at 300MHz). Thus for a practical 3m site, usable up to 1GHz, undulations less than 4.5cm in height are not significant.

In addition, the ground plane should be connected to the surrounding earth and to the mains protective earth and the ground plane material and any joints should be resistant to corrosion.

### *5.4.3 Other Practical Requirements*

Open area test sites are, by their nature, affected by the weather and consideration needs to be given to shelter for test equipment and personnel outside the obstruction free area as well as shelter for the equipment under test. Shelter for the equipment must necessarily be non scattering and thus non metallic, and care must be taken to ensure that water on the structure does not introduce unwanted scattering or absorption of the emissions. For precompliance testing it is usually most cost effective not to have any equipment shelter and only test in fine weather. ANSI C63.7-1992 gives an in depth treatment of the construction of open area test sites and RF transparent weather protection enclosures.

Minimising ambient signal levels is the most difficult aspect of choosing a site for an OATS and this often requires that the site is located in a remote area (typically in a valley where there is poor or no broadcast service reception). Power is also required for both the test equipment and the equipment under test and this may mean that generators are required at particularly remote sites. The practical problems with remote sites tend to result in pre-compliance sites being located on convenient locations where the problems of high ambient levels accepted as an unavoidable limitation.

## *5.5 Immunity Testing*

Apart from periodic calibration or verification of the various generators used there are no specific EMC measurements required when doing immunity testing. The basic procedure is to identify the critical operation functions of the equipment under test (EUT), apply the various electromagnetic phenomena and observe and record the functional operation of the equipment before, during and after the application of the test.

## *5.6 Layout and Configuration for EMC Testing*

The standards mentioned in the last chapter devote a great deal of their content to specifying test set up (layout) and test methodology because the results of EMC testing can be significantly effected by the way the equipment under test (EUT) and the test apparatus is arranged. The underlying philosophy of these standards is to specify a worst case operating arrangement for the EUT and a test layout which can be reproduced and which will, hopefully, yield repeatable results.

The general rule for EMC testing is that the EUT layout, configuration and operating mode should present the worst case for emissions or susceptibility and this may require some investigation of the behaviour of the EUT under different operating conditions. Usually the EUT is "fully featured" with all options and connecting cables installed and operating at full load or operated with test software that exercises all the features of the equipment.

### *5.6.1 Conducted Emissions Testing*

Detailed diagrams of the test set up requirements are given in the appropriate test standards and these should always be used as the primary source documents. CISPR and FCC differ on some points of detail regarding test set up but are very similar. Listed below are the basic requirements for conducted emissions testing in accordance with CISPR standards;

- The test shall be conducted on a ground plane of minimum dimension 2m x 2m (this is usually the floor of a screened room)

- The EUT shall be positioned 0.8m above the ground plane on a non conducting surface (eg. a wooden table 0.8m high)

- The rear of the EUT shall be 0.4m from a vertical extension of the ground plane (eg. a wall of a screened room)

- The LISN shall be placed on and securely earthed to the ground plane and shall be 0.8m from the EUT.

- Connecting cables shall be 1m long or any length in excess of 1m shall be bundled in a "figure 8" arrangement less than 0.4m in length.

- Additional requirements are specified for testing with a high impedance voltage probe.

A typical set-up for compliance conducted emissions testing is illustrated in Photo 5.1.

For pre-compliance testing a close approximation to the exact arrangement specified is normally adequate.

### *5.6.2 Radiated Emissions Testing*

The set up for CISPR tests for radiated emissions is specified for an Open Area Test Site in accordance with specifications discussed previously. The equipment is to be positioned at a specified measurement distance from the receiving antenna. This distance varies between standards and is generally determined by the size of the EUT. Standard test distances are 3m, 10m and 30m and the allowable emission limits vary with a 1/d relationship. For example, the limits specified for a 10m test distance can be increased by 10.5dB if testing at 3m. Tests at 3m are generally more convenient to perform due to the physical requirements of ground planes and obstruction free areas but if the maximum dimension of the EUT exceeds 1m then 10m tests are generally required in order to avoid near field effects. Tests at 30m are performed on very large equipment and such sites require particularly low ambients and sensitive test equipment due to the extremely low limit specifications (20dB below the equivalent 3m limits). Most pre-compliance tests are carried out at 3m due to limitations of space and test equipment sensitivity.

Non-Floor standing EUT is placed on a non conductive (eg. wood or plastic) turntable 0.8m above the ground plane and connecting cables to support equipment are placed in a typical arrangement and fixed in position. This set up arrangement is usually recorded photographically to enable the test set up to be reproduced if required. The EUT arrangement is then rotated through 360° during the measurement scans to find the orientation that gives the worst case emissions. This is normally achieved via remote control of the turntable to facilitate automated testing.

The receiving antenna also has to be scanned in height between 1m and 4m in both horizontal and vertical polarities to record the worst case emissions (where the direct and reflected wave reinforce). Also two different antennas are generally required to cover the radiated emission bands C and D. The antenna height scan and sometimes the antenna polarisation are also controlled remotely for automated compliance testing.

Even with fully automated test facilities and EUT that achieves compliance by a comfortable margin, the time taken to perform a complete compliance radiated emission test is in the order of 3 hours, not including the time involved with travelling to the remote site and setting up and dismantling the equipment.

Photos 5.2 and 5.3 show a typical set up used for compliance radiated emission testing. Figure 5.4 illustrates the basic arrangement of a radiated emission tests and highlights some of the sources of error involved with such measurements.

Photo 5.1 - Typical set up for compliance conducted emissions testing

Photo 5.2 - Typical set up for compliance radiated emissions testing (Remote OATS)

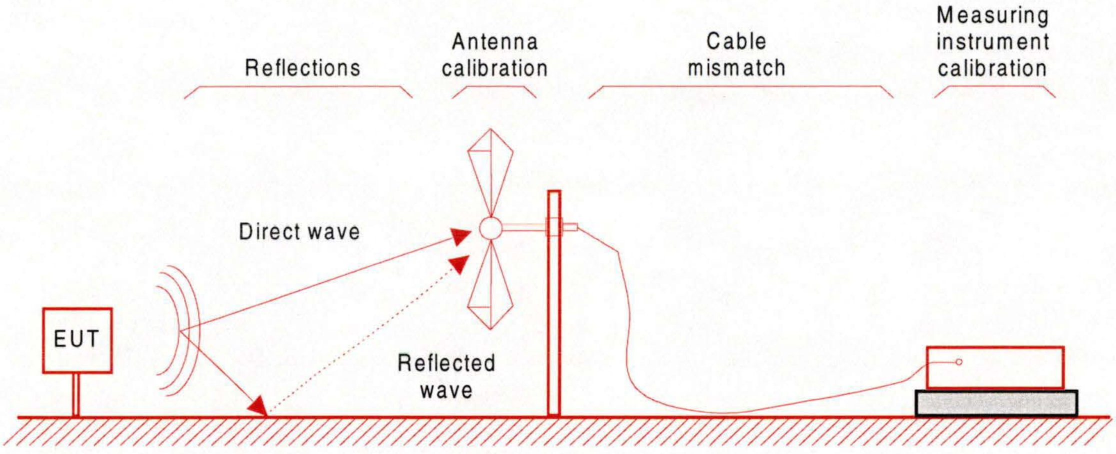



**Figure 5.4 - Radiated Emissions Testing**

*5.6.3 ESD immunity testing*

The set up for ESD immunity testing is detailed in IEC 1000-4-2 and requires a generator capable of producing the specified waveshape, polarity, level and type of discharge (air or contact). The key set up parameters specified in the standard are;

- Floor standing equipment shall be placed on insulating supports 10cm above the ground reference plane (eg. screened room floor) and earthed normally
- Table top equipment shall be placed on an insulating mat on 0.8m high wooden table with a conductive top (eg. a copper sheet) which forms a horizontal coupling plane
- A 0.5m square copper sheet spaced 0.7m from the EUT shall be used as a vertical coupling plane.
- The vertical (and horizontal) coupling planes shall be connected to the ground plane (eg. the screened room floor) via bleed resistors (2 x 1MΩ + 2kΩ in series)
- Air and contact discharges shall be applied to the equipment and to the horizontal and vertical coupling planes at the appropriate level specified in the standard.

A full ESD immunity test can involve many hundreds of discharges at various points on the equipment in order to locate any susceptibility.

*5.6.4 EFT Immunity Testing*

The test set up for EFT immunity testing is detailed in IEC 1000-4-4 and a representative set up for compliance testing of "floor standing" or rack mounted equipment is illustrated in Photo 5.4. This layout shows the long capacitive clamp used to capacitively couple the EFT burst pulses onto load and signal cables while coupling to mains power cables is via a specified coupling network built into the generator. The capability of the generator must incorporate the standard pulse shapes, repetition rates and voltage levels specified in the standard.

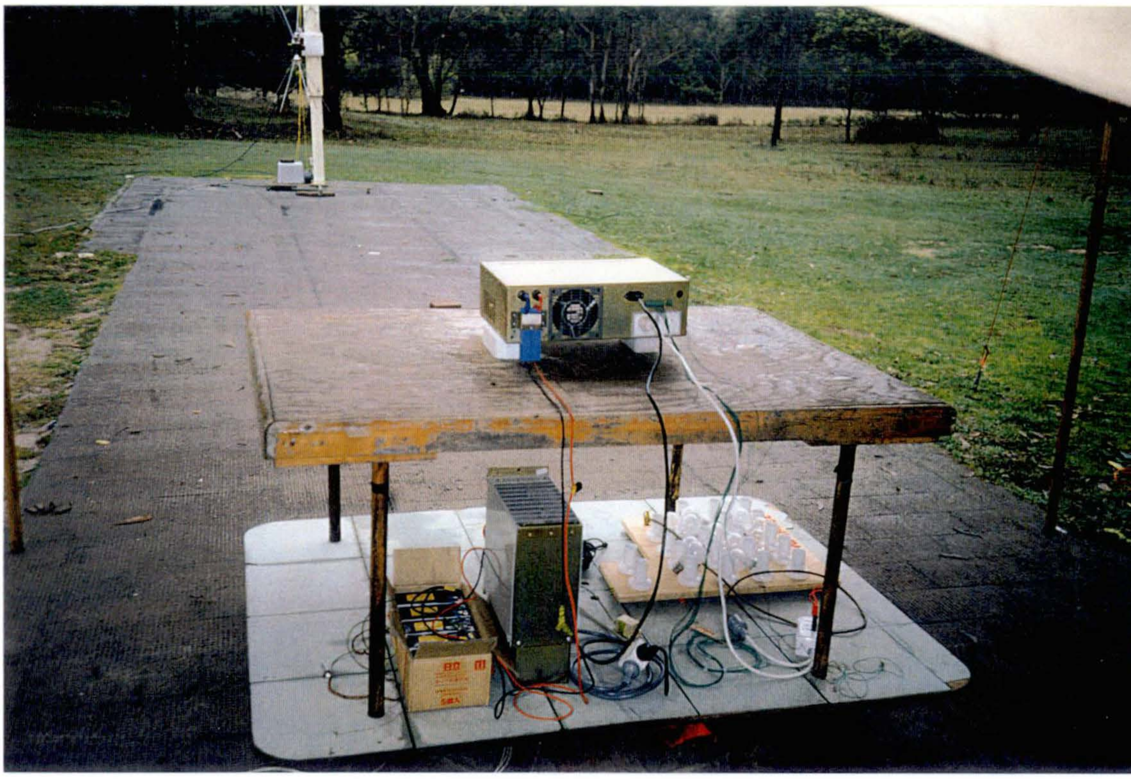


**Photo 5.3 - Compliance radiated emissions testing (EUT set up)**

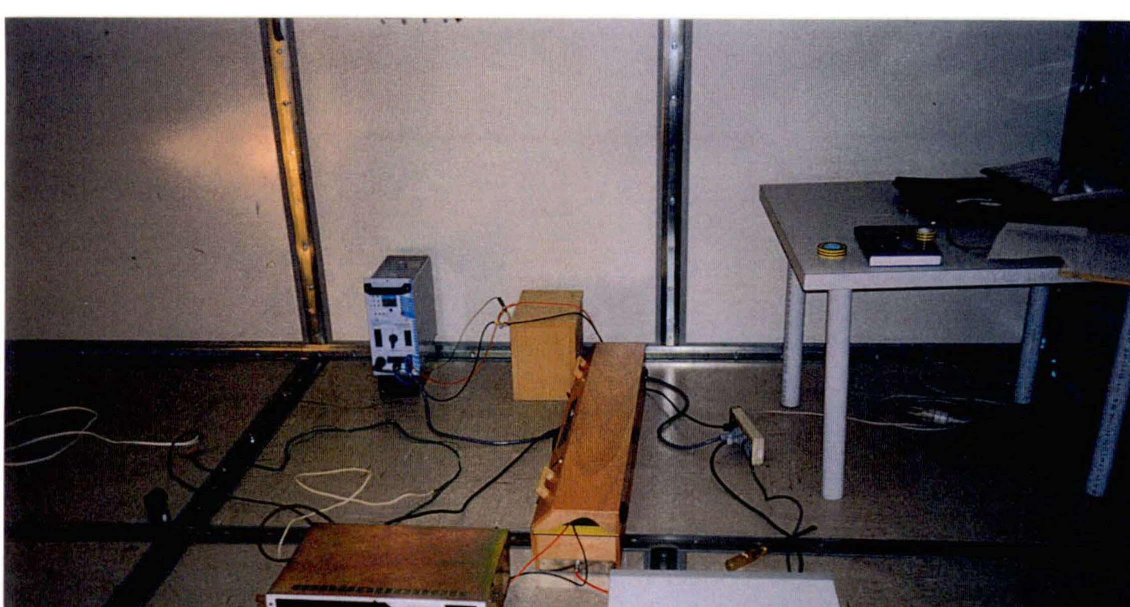


**Photo 5.4 - Compliance Electrical Fast Transient (EFT) burst immunity testing**

*5.6.5 Radiated RF Field Immunity Testing*

The test set up required for radiated RF field immunity testing is perhaps the most extensive required by any of the EMC tests. A typical compliance test set up is illustrated diagrammatically in Figure 5.5.

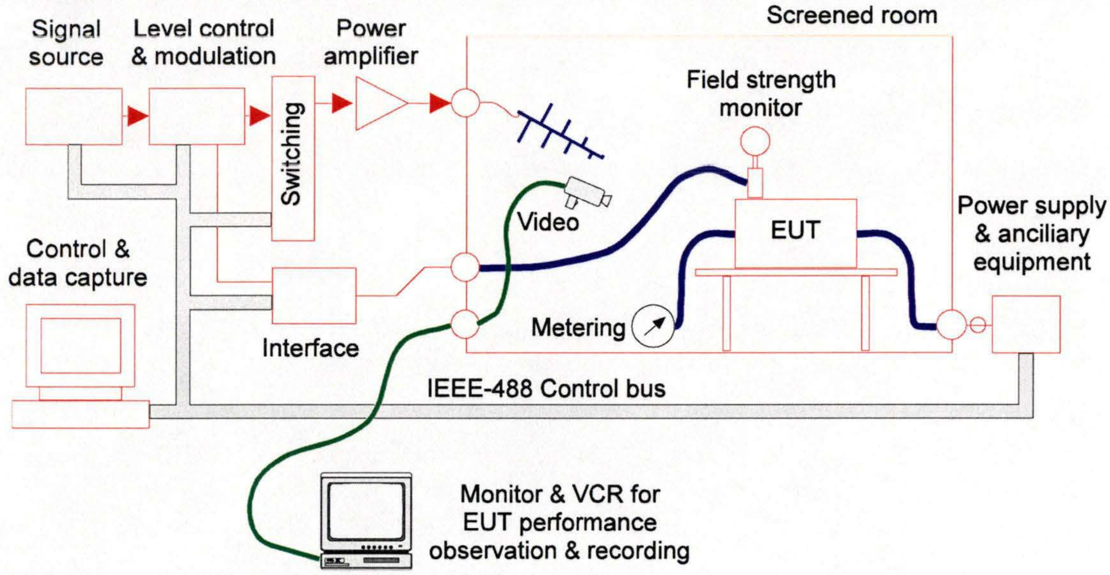



**Figure 5.5 - RF Radiated Field Immunity Test Set Up**

The equipment under test is positioned in a large screened room and a field strength monitor located on or adjacent to the EUT. Connections to support equipment and power supplies are fed into the screened room via suitable filtering and a suitably shielded video camera and metering are positioned in order to monitor the function of the EUT.

The specified signal is an RF carrier which is 80% amplitude modulated at 1kHz. This signal is fed to a suitable RF power amplifier the output of which is connected to a suitable broadband antenna in the screened room. The RF field monitor output is fed back to control the output level of the amplified signal thus forming a control loop which can be used to generate a set field strength at the EUT. The frequency of the RF signal is stepped in suitable increments from 27MHz to 1GHz with a dwell time of a few seconds at each frequency. This requires the use of two broadband antenna types (and often two broadband power amplifiers), typically a Biconical Antenna for 27MHz to 300MHz and a Log Periodic Antenna for 300MHz to 1GHz with tests performed with horizontal and vertical antenna polarisations. The test is usually automated using a controlling computer and an IEEE-488 instrument control bus, but even so, 3 to 4 hours may be required for a complete test. Photo 5.5 shows a compliance test house set up for radiated field immunity including the a field strength monitor on top of the EUT, the radiating antenna (in this case a vertically polarised Log Periodic antenna) and the shielded video camera. Photo 5.6 shows the controlling equipment and monitor screen outside the screened room where the performance of the equipment is observed during the test sequence.

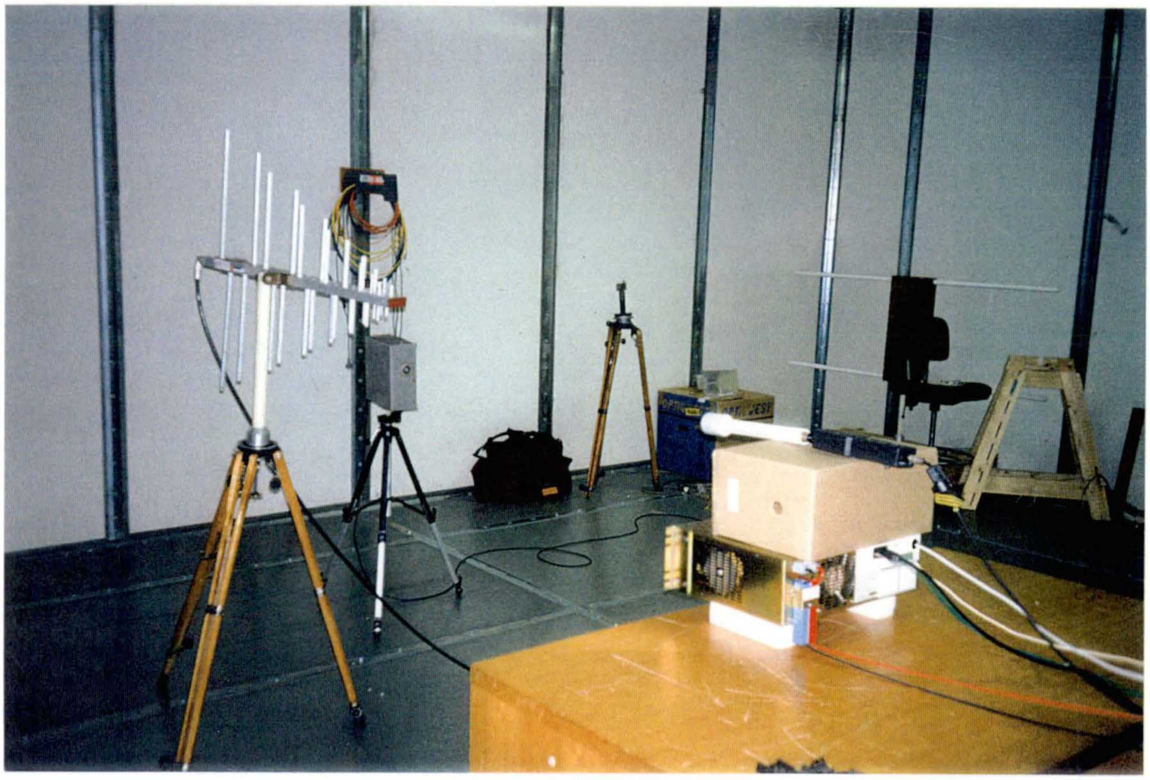


**Photo 5.5 - Radiated RF immunity testing (inside screened room)**

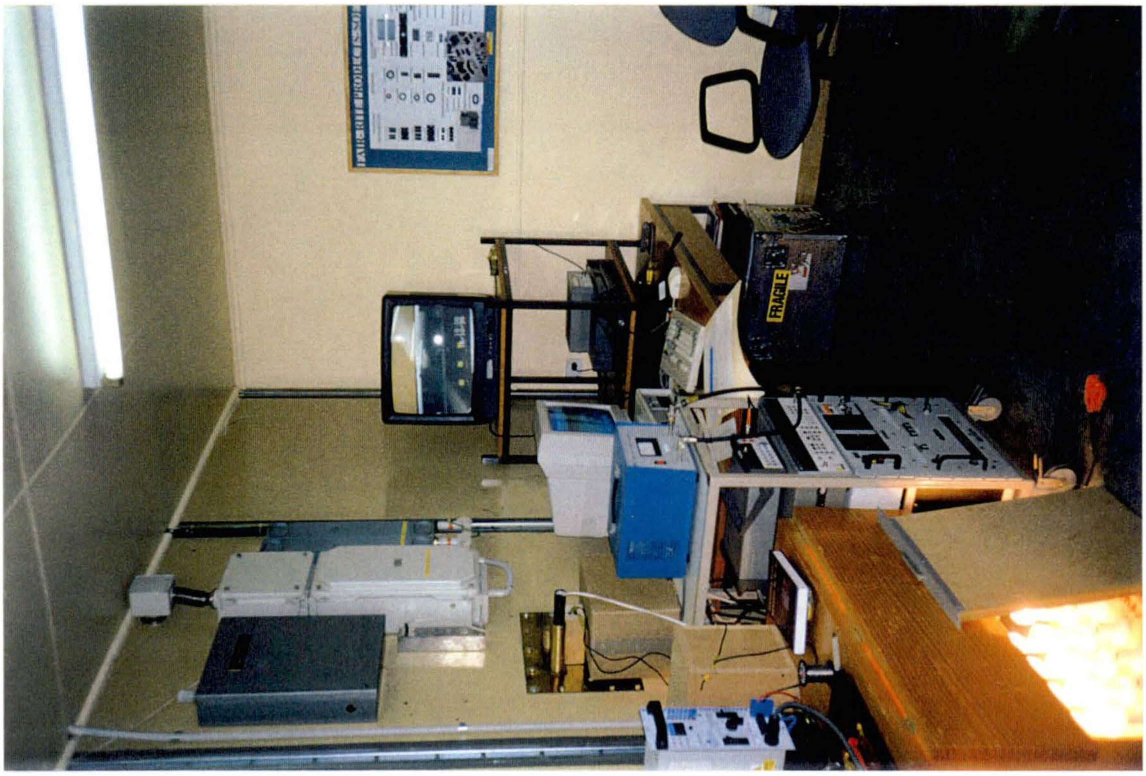



**Photo 5.6 - Radiated RF immunity testing (control and monitoring equipment)**

# 6. Establishing In-House Testing Facilities

## *6.1 Justification*

The justification for investing in in-house testing facilities is primarily based on time and money. It is conservatively estimated that more than 80-90% of products submitted for testing without some precompliance testing being conducted, fail to achieve compliance. In addition, the average number of iterations for such a product to achieve compliance is around 2.5. With the total charges for compliance testing at a certified test house (including the cost of involvement of the design engineer) currently running at around $2k per day and the average testing time being 3 days for emissions and immunity testing, it is easy to justify an investment of about $50k in pre-compliance test equipment and facilities on the basis of reducing compliance testing iteration costs alone. Another justification for establishing test facilities in-house is that it also brings EMC familiarity and expertise in-house which should have long term payoffs in higher quality and more cost effective EMC design techniques.

Hewlett Packard have conducted studies which reveal that "the real cost of failing EMC testing at a test house is not the re-testing charge, it is the inability to place the product on the market"[20]. This delay in time to market increases the break even point in recovering development costs typically by a factor of two and reduces the potential sales by typically 20%. For this reason, Hewlett Packard invests around $30M (0.1% of its revenue) in extensive in-house compliance EMC testing facilities.

This chapter outlines the requirements for cost effective EMC test facilities for small to medium sized companies (rather than multi-nationals like HP). This is essentially a summary of the author's efforts in establishing suitable EMC test facilities at minimal cost.

## *6.2 Emission Measurement Apparatus*

### *6.2.1 Spectrum Analyser*

The basic tool for any EMC emissions measurements is a spectrum analyser. For pre compliance testing, low to medium cost instruments are available which offer all the features necessary for testing in accordance with the standards. Modern spectrum analysers, offer many "ease of use" features over the more accurate (and more expensive) dedicated EMI receivers available. As detailed in the previous chapter, there are a few traps to be wary of when using spectrum analysers for EMI measurements and these include;

- Possibility of undetected overload (compression) of the wide bandwidth RF input. This can be tested for by checking that applying a set attenuation reduces the signal by the correct amount. Also many software packages for automated EMI testing have a "compression test " feature.

- The sensitive RF input stage is prone to damage and appropriate transient limiters should be employed.

The "noise floor" of cheaper instruments may approach the levels required to be measured in some EMI tests.

The essential features of a pre-compliance spectrum analyser include;

- Frequency sweep range of 9kHz to greater than 1GHz (9kHz - 1.8GHz typical)
- CISPR specified resolution bandwidths of 200Hz, 9kHz and 120kHz
- CISPR Quasi-Peak detector in addition to peak and average detection capability
- Digital storage and peak hold facility
- Noise floor lower than -100dBm (no input signal)

Other features required for ease of measurement and diagnostics include;

- IEEE 488 instrument bus interface for programmed control of the instrument
- Dedicated software for performing standard measurement sequences in accordance with the various standards
- A portable PC with IEEE 488 interface card for running software and storing and analysing results
- Instrument settings storage and recall facilities
- On screen limit line display facility
- Facility for applying stored correction factors for various transducers
- Audible output from AM and FM demodulation (for identifying radiated ambients)

Various available instruments were investigated against the above requirements and a "Tektronix" spectrum analyser and software combination was selected as the most cost effective solution. This instrument along with a suitable "docked" notebook computer system is shown in Photo 6.1 This complete system cost in the order of $25k.

Extended ("desirable") features include;

- In built tracking generator for frequency responses and filter and shielding characterisations.
- Frequency preselector to avoid input overload (compression).

### *6.2.2 Line Impedance Stabilisation Network (LISN)*

As discussed in chapter 5, a LISN is necessary to make conducted emission measurements on mains power cables in accordance with CISPR and ANSI

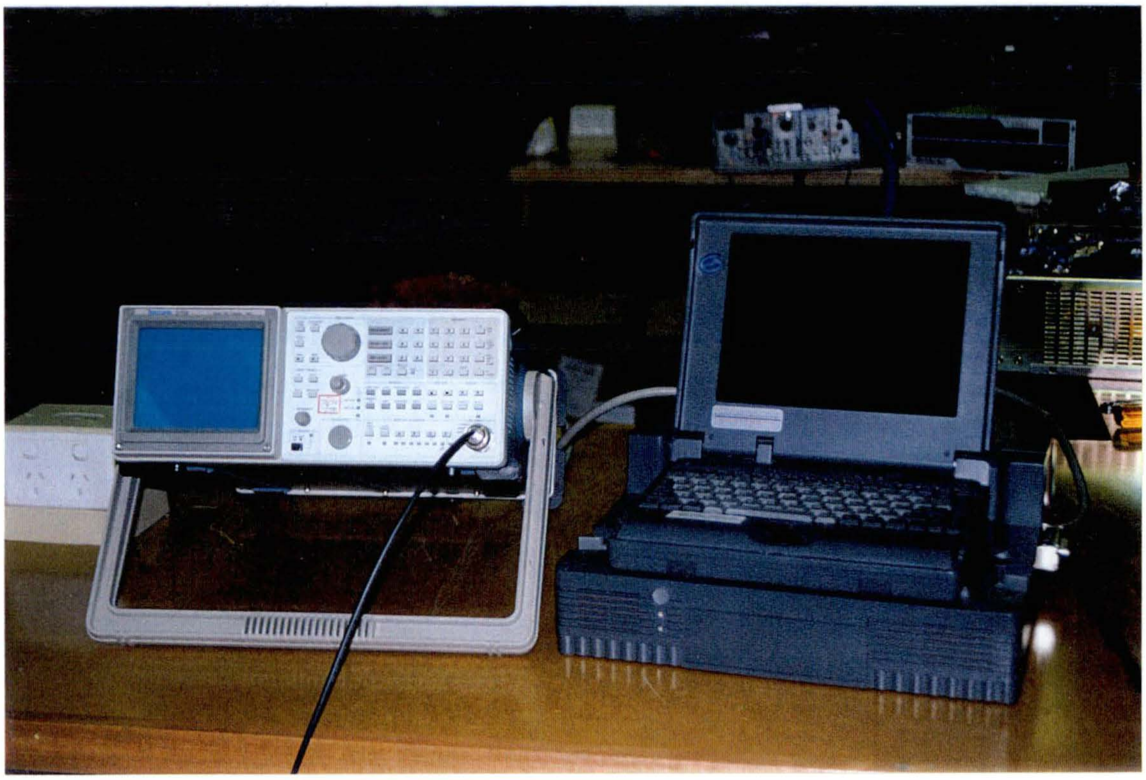


**Photo 6.1 - Spectrum Analyser and "docked" notebook computer (Controller)**

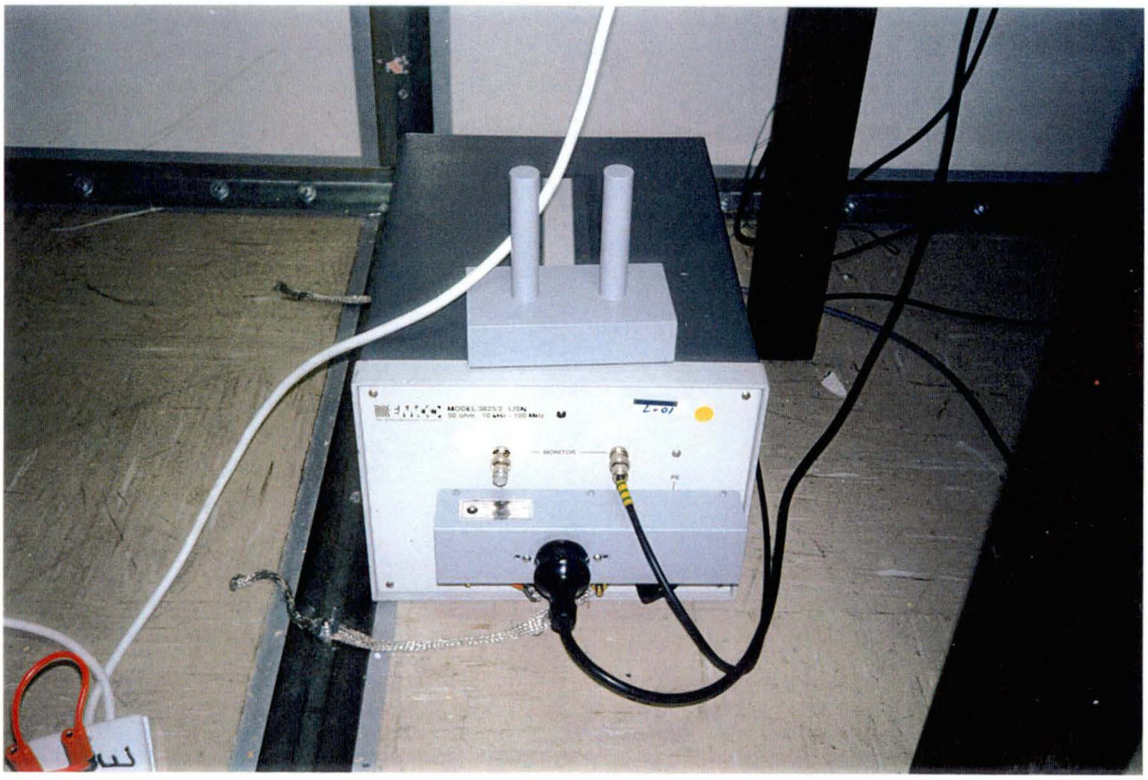


**Photo 6.2 - 240VAC Single Phase (2 wire), 25Amp LISN (used for certified tests)**

standards. The LISN provides a specified impedance (50Ω/50μH + 5Ω) for measuring conducted RF interference voltages from 150kHz to 30MHz. Some standards (currently in draft form) call up the use of a LISN when measuring conducted interference on DC power ports and extend the measurement frequency range down to 20kHz. Whilst it is possible to construct LISN networks from discrete components in accordance with the specifications given in CISPR 16, it is normally far more cost effective to purchase a suitable commercially available LISN unit.

The following specifications need to be considered when building or purchasing a LISN unit;

- Single or Three Phase: Is the equipment to be tested, powered from single phase (two wire) or three phase (three or four wire) supplies? A separate LISN circuit is usually included for each phase and neutral with a 50ohm output connector (usually BNC) as a measurement point for each line.

- Maximum Working Voltage: What is the maximum working voltage on the power supply lines to be measured? This sets the voltage ratings on the shunt capacitors used in the network. This is typically 240VAC/415VAC for single and three phase supplies.

- Maximum Load Current: Generally, equipment exhibits maximum emissions at full load and thus the series elements (connectors, conductors and inductors) must be rated for the maximum load current expected to be drawn.

The particular LISN unit purchased by the author for in house tests is illustrated in Photo 6.3 and (coincidentally) was identical to the compliance test house unit illustrated in Photo 6.2 (approximate cost $5k). This unit is rated for 240VAC, 25Amp single phase supplies and is in accordance with CISPR specifications for conducted interference measurements in Band A (10kHz - 150kHz) and Band B (150kHz - 30MHz). This unit is also suitable for most DC power port measurements up to 25A load current.

It should be noted that flying leads attached to the output terminals of a LISN introduce unacceptable variability for precise calibration at higher frequencies and thus wiring connections to the equipment supply outlet (GPO) must be fixed in a screened termination box as illustrated in Photo 6.2. The two wooden pegs shown on top of the LISN are used for bundling any excess power supply cable (ie. greater than 1 m in length) in a "non-inductive" figure-8 arrangement as specified in CISPR standards. Photo 6.3 shows an identical LISN used for pre-compliance with short flying leads attached. Also shown is a transient protector on one of the 50Ω BNC measurement ports with the unused port terminated in 50Ω as required. The transient limiter protects the sensitive RF input of the spectrum analyser from transients resulting from power supply switching to the equipment.

A LISN, like any transducer or piece of test and measurement equipment. should be periodically calibrated. Traceable calibration is particularly important for compliance test results. For pre-compliance tests the calibration data supplied by the manufacturer is generally accurate enough for most purposes. The correction factors for the LISN

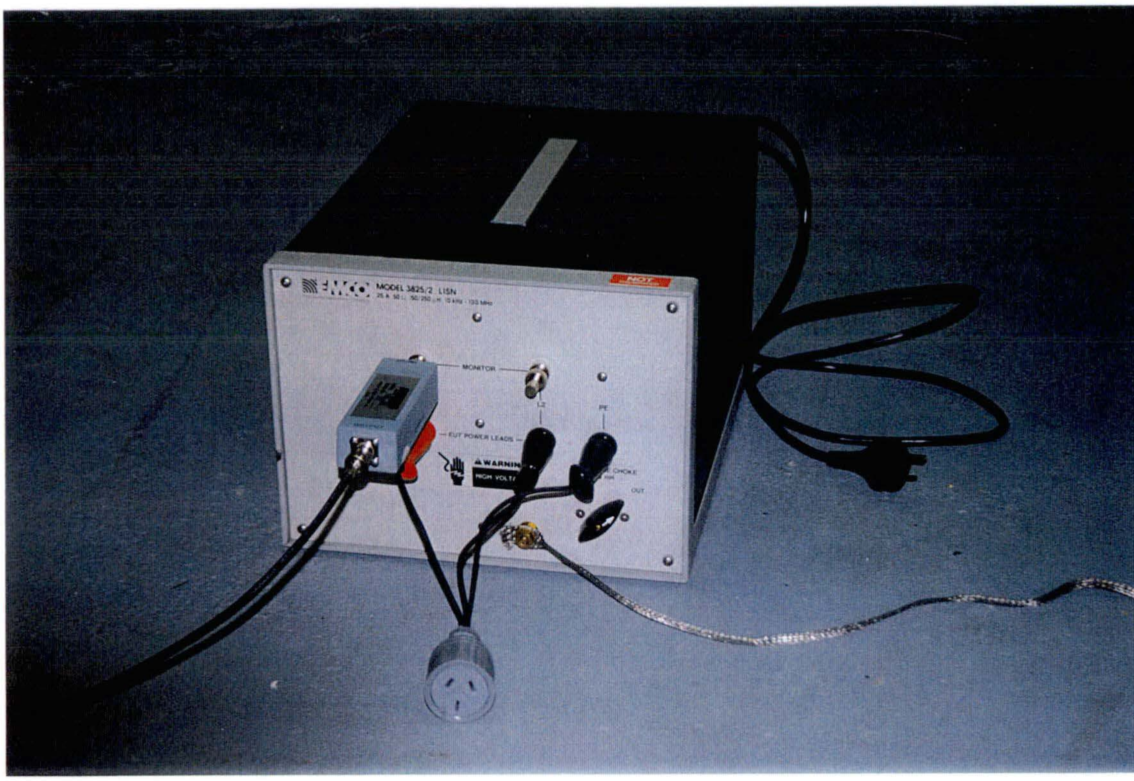


Photo 6.3 - 25 Amp "pre-compliance" LISN with transient limiter


Photo 6.4 - Biconical Antenna being used for pre-compliance emission measurements

are entered as transducer factors in the controlling software for the spectrum analyser in order to get a corrected emissions limit line displayed on the analyser screen. The attenuation presented by the combination of the pre-compliance LISN, transient limiter and cable connections is "flat" at approximately 13dB over the CISPR band B (150kHz - 30MHz) frequency range.

**SAFETY WARNING:** The circuit specified for a LISN involves a total of about 10μF of capacitance connected between line and ground. For this reason, when a 240VAC supply is connected, about **0.75A** of earth leakage current flows. This is extremely hazardous and precludes the use of LISNs on earth leakage protected circuits. A LISN should always be permanently and securely bonded to protective earth (usually to a screened room floor) and due caution used when power is applied.

### *6.2.3 High Impedance Voltage Probe*

For conducted noise measurements on some types of output ports (eg. auxiliary alarm contacts and AC load ports) a high impedance probe (sometimes called a high voltage probe) is specified by CISPR. This is used to measure noise voltage in the range 150kHz - 30MHz and consists of an AC coupling capacitor and a series resistor connected to the centre conductor of a 50Ω coaxial cable. For pre-compliance tests such a probe was constructed (as outlined in CISPR 14) using a 22nF, 250VAC, Y-grade capacitor and a 1500Ω resistor (minimal cost). The capacitor impedance is negligible above 150kHz and thus the probe introduces an attenuation of approximately 30dB at the 50Ω input to the spectrum analyser and this must be entered as a correction factor for the displayed limit line.

### *6.2.4 Antennas*

For radiated emission measurements a broadband antenna is required. In order to cover the required frequency range of 30MHz to 1GHz, two different broad band antennas are required as discussed in the previous chapter on EMC measurements.

Given the type of Switch Mode Power Supply and low frequency microcontroller apparatus to be tested it was decided to initially compromise and only purchase a Biconical antenna covering the 30MHz - 300MHz range (approximate cost $4k). The particular antenna selected is illustrated in Photo 6.4 where it is shown in use on initial tests on the pre-compliance "car park" Open Area Test Site discussed later. This particular antenna is collapsible to allow easy transportation. The antenna factors supplied in the manufacturers calibration tables were entered as transducer factors in the controlling software for the spectrum analyser. These are shown in Graph 6.1 and allow software corrections to convert the voltages measured by the spectrum analyser (in dBm or dBμv) to the field strength being measured at the antenna (in dBm/m or dBμv/m). In addition the loss due to the cable and connections needs to be allowed for and this was calculated from manufacturers data and is displayed in Graph 6.5.

Emissions in the higher frequency range (300MHz to 1GHz) are usually measured using a log periodic antenna. An example of a log periodic antenna being used for compliance radiated field immunity tests is illustrated in Photo 6.5.

Photo 6.5 - Log Periodic Antenna being used for radiated field immunity tests

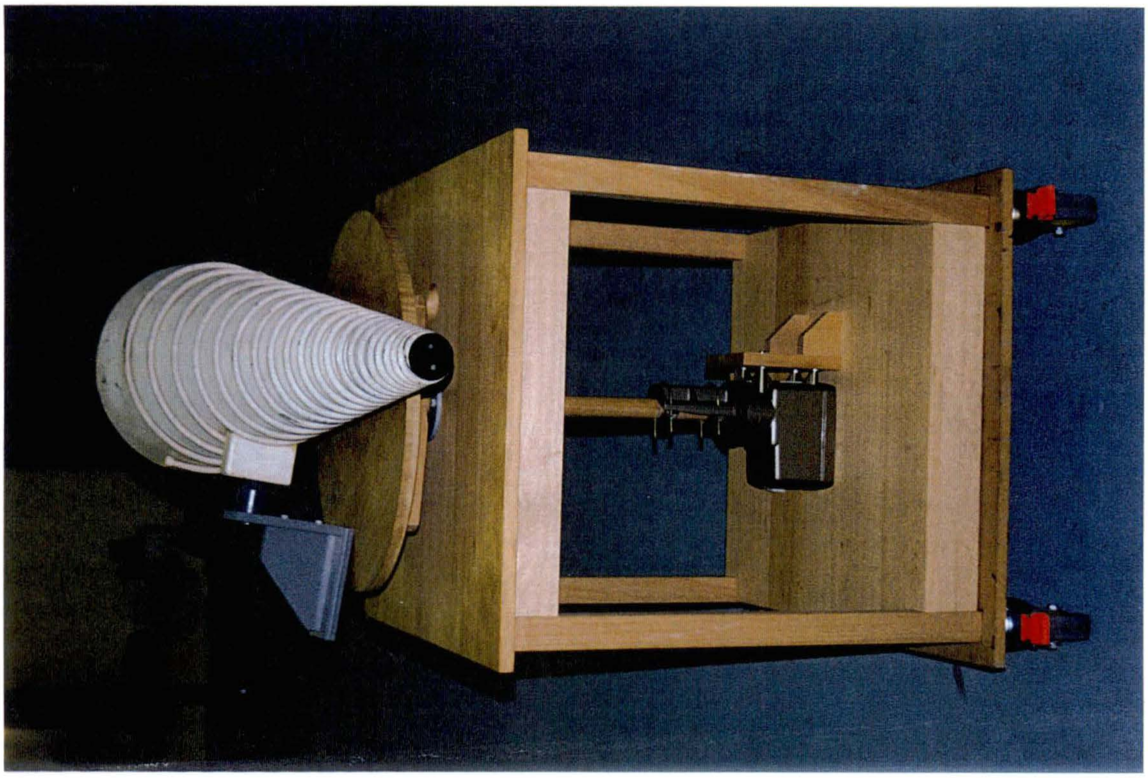
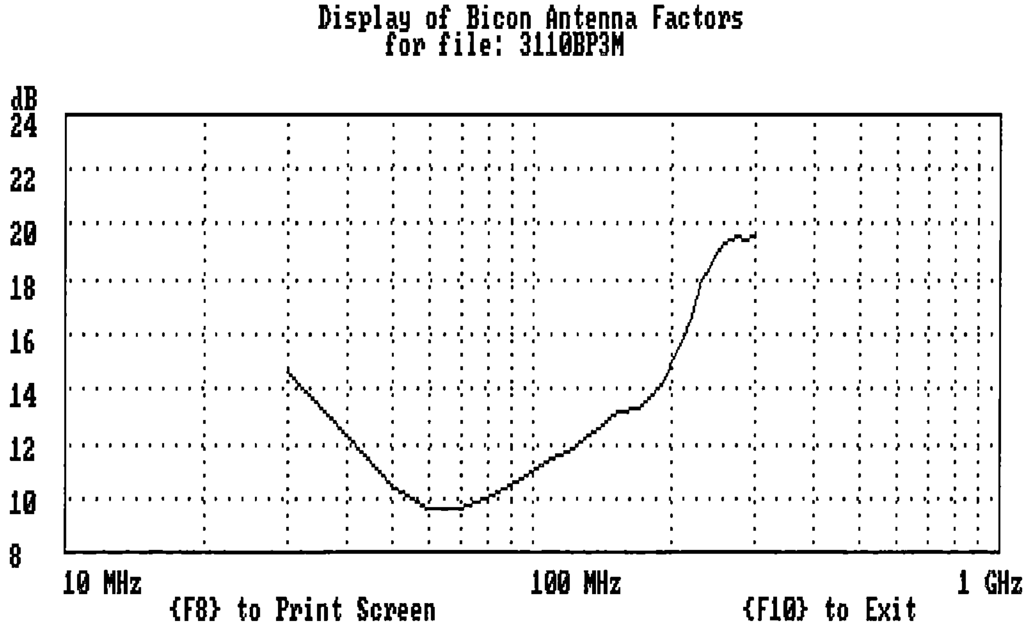


Photo 6.6 - Conical Log Spiral Antenna

After initial pre-compliance radiated emissions tests had been made, a second hand Conical Log Spiral antenna was acquired at very low cost (approx. $400.00) to provide the extra capability of some form of high frequency emission measurement. The Conical Log Spiral antenna acquired is illustrated in P6.6 and covers the frequency range 300MHz to 1GHz. This is a very directional, circularly polarised antenna which can be used to measure horizontal or vertical linearly polarised signals by applying a 3dB increase to the circularly polarised antenna factors due to the polarisation coupling loss. As an alternative to the preferred Log Periodic antenna, the Conical Log Spiral is less efficient, has lower gain and has much worse VSWR properties but, as the saying goes "beggars can't be choosers". Given the expected limited requirements, this particular acquisition provided a cost effective limited facility for making high frequency radiated emission measurements.

### *6.2.5 Diagnostic Probes*

Another essential item in a pre-compliance test set is a collection of diagnostic or "sniffer" probes. E-field probes can be made by simply removing the screen from around a length of the inner conductor at the end of a piece of coaxial cable. H-field probes can be made by forming a loop at the end of piece of coaxial cable with the inner at the end of the cable connected to the screen of the cable at the point where the loop is completed. Alternatively, neatly packaged, off the shelf probe kits as shown in Photo 6.7 can be purchased (approx. cost $1k). These probes are useful for locating the source and identifying the type of emission from a section of circuitry. The sensitivity of an E-Field probe increases with the length of the unshielded conductor but the ability to pin point noise sources decreases with the increase in probe size. Similarly, the sensitivity of an H-field probe increases with its loop area but its selectivity decreases. Measurements made with these sort of probes are usually qualitative or comparative rather than absolute.




**Graph 6.1 - Antenna Factors for EMCO Model 3110BP Biconical Antenna**

**Photo 6.7 - Set of diagnostic E and H field probes**

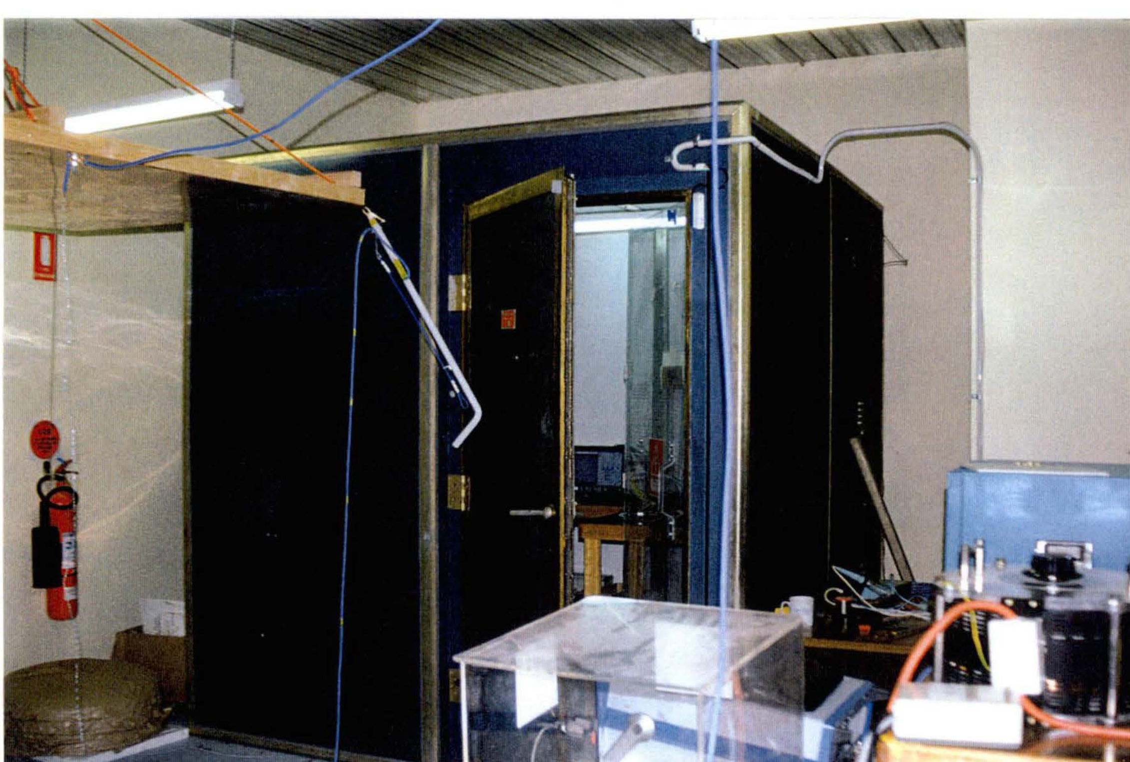
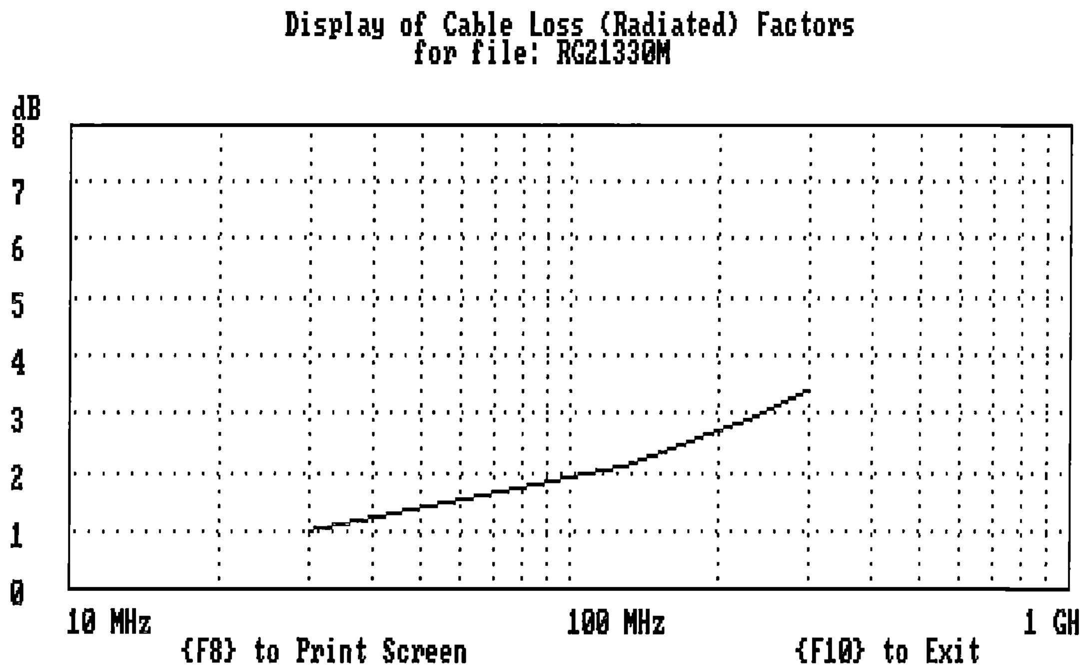


**Photo 6.8 - 2m x 2m Belling and Lee screened room for pre-compliance tests.**




**Graph 6.2 - Cable Loss Attenuation Factors for 30m of RG213 Cable**

*6.2.6 Screened Room*

This is not an essential item for pre-compliance tests but a screened room is a very convenient facility to have in order to perform repeatable pre-compliance measurements in accordance with the standards. The most basic screened room is usually a 2m x 2m enclosure and such a room enables the exclusion of ambients from investigative and diagnostic measurements as well as enabling the emissions generated by immunity tests to be contained.

One very useful application of a screened room is to perform a radiated emissions pre-scan in the absence of ambient noise in order to characterise the radiated emission profile of the equipment under test. This allows problem frequency ranges to be identified and any narrowband noise identified which may coincide with (and hence be masked by) an ambient in the open area test site measurements.

The author was fortunate enough to already have access to a 2m x 2m Belling and Lee screened room prior to establishing in-house EMC test facilities and this is illustrated in Photo 6.8.

*6.2.7 Open Area Test Site*

The OATS facility established by the author for "look-see" measurements (prior to submitting a prototype to a compliance test house) was not intended to meet the stringent requirements of a certified test site as detailed in the chapter on EMC measurements but rather offer a convenient, low cost, practical site for design confidence checks. The notional uncertainty target for this site was 10dB. As mentioned previously, the frequency range of primary interest (due to the type of

SMPS equipment to be tested on this site) was 30MHz - 300MHz which can be adequately measured using a single biconical broadband antenna.

The initial open area test facility established by the author is illustrated in Photos 6.9 and 6.10. This facility makes use of the company car park as a relatively flat obstruction free area handy to shelter and services. The ground plane is constructed from rolls of 2.5cm square "weld mesh" soldered together and can be rolled up and stored when not in use. Earth rods driven flush with the surface of the asphalt and threaded in the top, provide earth connection points at diagonal corners.

### *6.2.8 Turntable (Remotely Rotatable)*

For open area radiated emissions tests, the equipment under test must be rotated slowly through 360° to determine the worst case orientation for emissions. During this process the spectrum analyser is set on peak hold to record emission peaks and azimuths for the corresponding equipment orientation can be noted. This is most conveniently done via remote control while observing the analyser output. A turntable for this purpose was constructed with the following features;

- top of turn table 0.8m above ground plane in accordance with standards
- all wooden (dowelled and glued) construction to minimise RF reflections
- rotation control via a commercial antenna rotator and control module
- size appropriate for type of equipment under test (approximately 1m square)

This turntable can be seen in Photos 6.4 and 6.6

### *6.2.9 Antenna Mast (Manually Adjustable)*

In addition to rotating the equipment, the antenna height must be scanned (for both vertical and horizontal polarisation) from 1m to 4m to locate the maximum emissions at each of the swept frequencies. This occurs when the reflected and direct waves are in phase. Again this is best done by remotely raising and lowering the antenna on a mast and observing the spectrum analyser peak hold output. Some well equipped compliance OATS have a mast with an antenna carriage that can be raised and lowered remotely and rotated between horizontal and vertical polarisation's using compressed air.

Two masts were constructed for in-house precompliance tests, one compact mast allowing manual height adjustment (and antenna polarisation) up to about 2m high for initial measurements (see Photo 6.4) and one full height mast with a manually winchable antenna carriage covering the full 1-4m range (see Photo 6.10). Both of these masts were constructed from plastics with any conductive parts (scatterers) above the ground plane minimised and kept as small as possible (metal screws etc.). In addition, the full scan mast utilised a piece of plastic conduit for final tests to extend the coaxial cable directly back 1m from the mast before it fell to the ground to


**Photo 6.9 - Pre-compliance Open Area Test Site (OATS) located in a car park**

**Photo 6.10 - Calibration measurements on car park OATS**

reduce reflections from the cable screen (particularly significant for vertical polarisation measurements).

### *6.2.10 Tuned Dipole Antennas*

While not essential for making equipment measurements, a set of tuned dipoles covering the frequency range of 27MHz to 1GHz are invaluable for making site attenuation and other calibration measurements. Such a set of antennas manufactured by Singer (purchased second hand - approximate cost $400.00) is illustrated in Photo 6.11. These antennas may also come in useful for transmitting significant RF power for spot RF immunity tests in a screened enclosure.

### *6.2.11 Accessories*

Various specialised accessories are useful for EMC RF measurements. A selection of these including, a low noise, broadband preamplifier, connector adaptors, in-line BNC attenuators or pads (3dB, 6dB and 10dB are the most useful) and BNC "T" connectors with 50Ω terminators (for making insertion loss measurements) are illustrated in Photo 6.12.

## ***6.3 Immunity Measurement Apparatus***

Generally, in house, pre-compliance immunity test apparatus is expensive and specialised and more difficult to justify as cost effective. Electrostatic Discharge (ESD) testing is the one facility that should be seriously considered when budgeting on a minimal precompliance set up. As the company with which the author is affiliated is involved with surge and transient protection as core business, a higher profile was placed on having in-house facilities for all of the transient immunity tests required.

### *6.3.1 ESD*

Considered as one of the more onerous tests, ESD represents a very fast rise time transient which can damage unprotected components but which also produces a very broadband localised RF field and can be used as a rough guide for RF immunity. Calibrated generators producing air and contact discharges in accordance with IEC 1000-4-2 are available for around $10k. Such a generator was purchased for in-house tests and this is illustrated in action in Photo 6.13. Here an air discharge (from a 15kV source) is visible between the probe tip of the ESD gun and the front panel push button of the equipment under test.

### *6.3.2 EFT*

EFT burst generators are also specialised and relatively expensive items of test equipment (approximate cost $20k) and are not generally considered for a low budget pre-compliance test set. Such an item was however purchased as part of the pre-compliance apparatus described here and is illustrated in Photo 6.14 with a full test arrangement including a capacitive coupling clamp illustrated previously in Photo 5.4. The key features to consider for an EFT burst generator include;

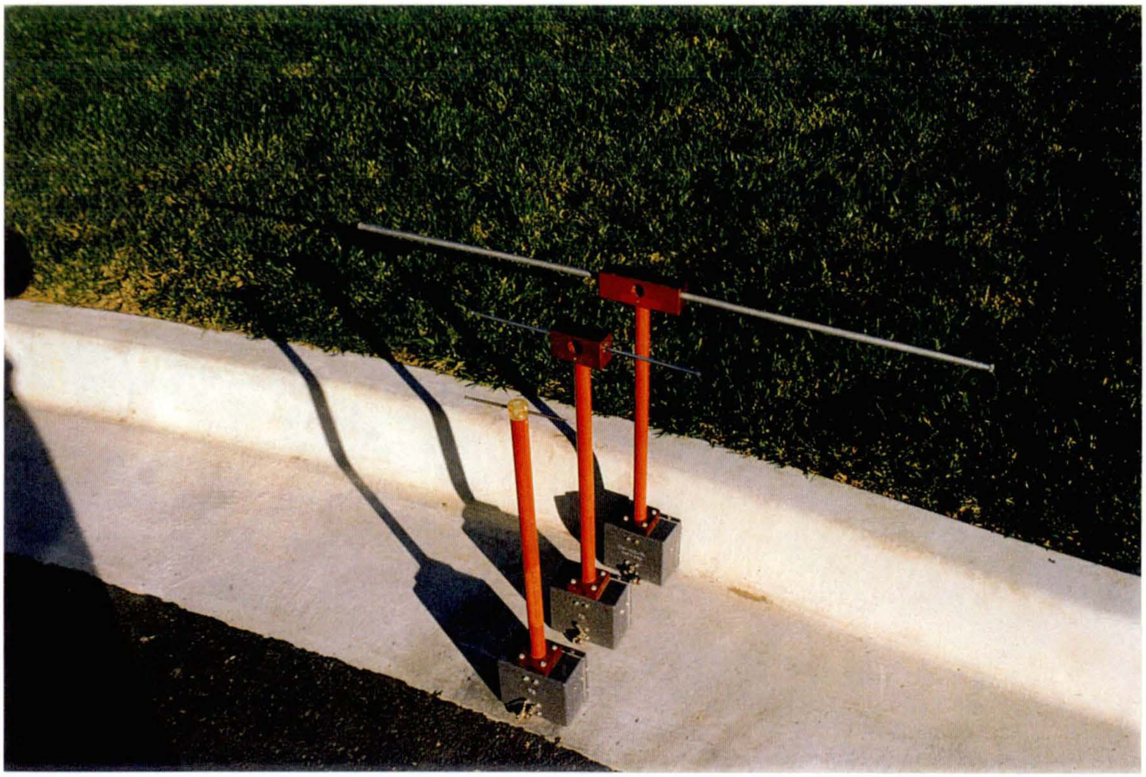


Photo 6.11 - Set of tuned dipole antennas (30MHz - 1GHz)

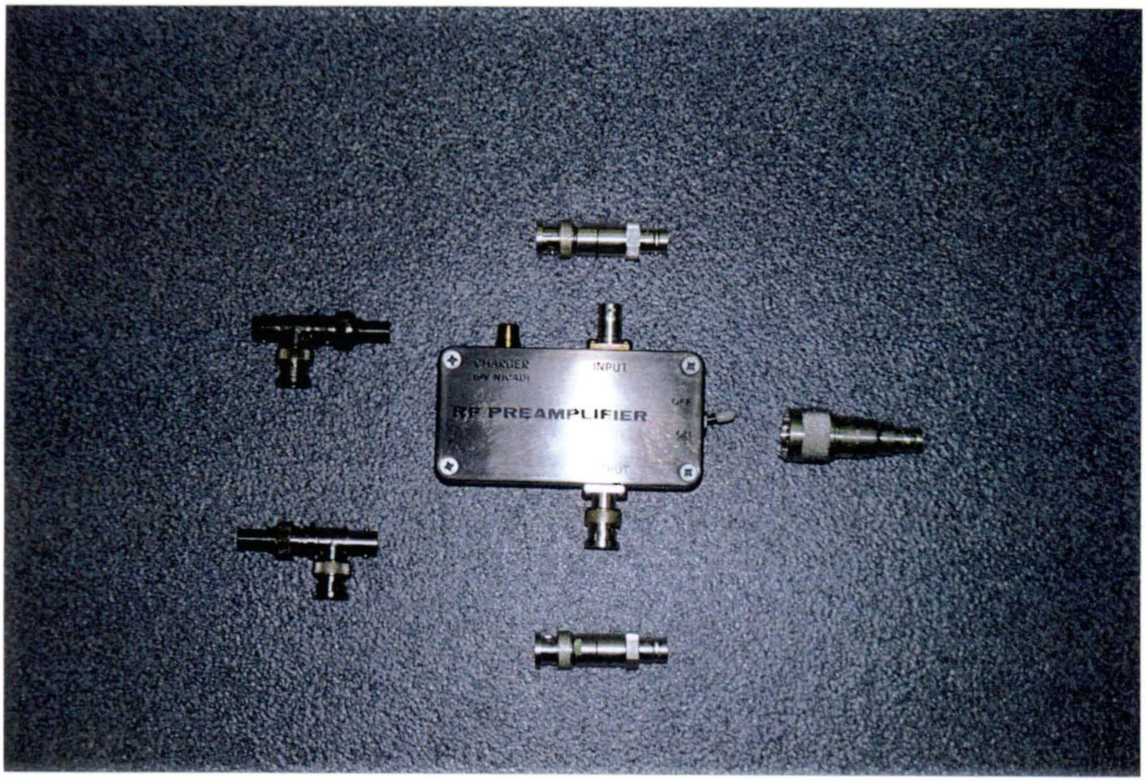



Photo 6.12 - RF accessories for EMC measurements

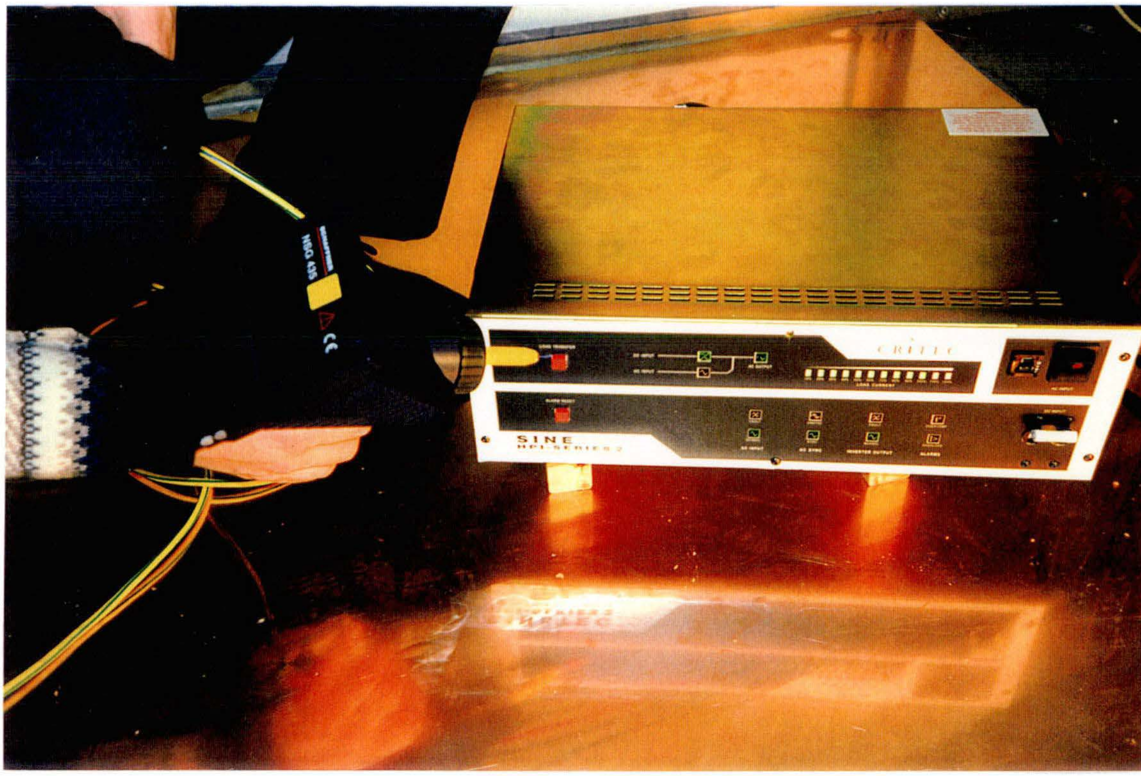



**Photo 6.13 - Electrostatic Discharge generator (air discharge pre-compliance testing)**

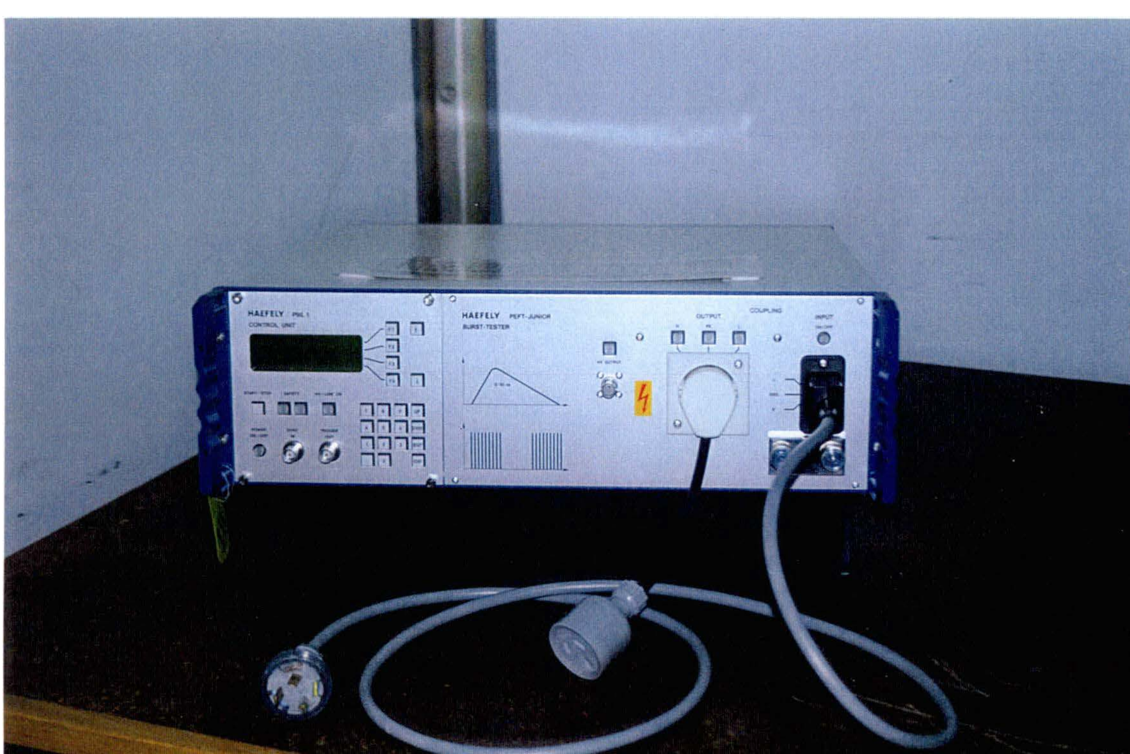



**Photo 6.14 - Electrical Fast Transient burst generator for pre-compliance testing**

- Full IEC 1000-4-4 capability
- Ability to program and store test sequences
- Automatic test summary report generation
- Appropriately rated mains line coupling unit
- Compatible capacitive clamp for coupling bursts onto signal lines
- Flexibility to generate higher pulse repetition frequencies (up to 1MHz)
- Interface for incorporation into automated test software

### *6.3.3 Transient Surge*

Transient Surge generation in accordance with IEC 1000-4-5 is also an expensive specialised capability not normally considered for low budget pre-compliance testing. Such generators generally have to be mated with an appropriately rated mains line coupling unit and have to have a peak pulse capability of at least 4kV/2kA for a 1.2/50µS - 8/20µS dual mode transient. The author was fortunate to have access to an ANSI C62 standard generator (and 20A line coupling unit) with a peak pulse capability in excess of 6kV/3kA (see Photo 6.15) as well as a custom built 5kV 10/700µS generator. This equipment can be easily adapted to perform IEC 1000-4-5 tests. Indeed the current in-house transient surge generation capacity extends to 20kA - 8/20µS and will soon include 150kA - 8/20µS and 20kA - 10/350µS "direct lightning" capacity as specified in proposed IEC standards on lightning protection.

### *6.3.4 Immunity to Radiated RF Fields*

Performance of radiated immunity tests generally requires the use of specialised, medium power RF equipment and a large screened room or expensive TEM cells which are limited in the equipment size that they can accommodate. This is another capability that is not usually considered for pre-compliance testing although some inexpensive "look-see" measurements can be performed. An example of such a measurement is to operate a GSM mobile phone near the equipment with the transmitting antenna in very close proximity and at various orientations to all surfaces and apertures of the equipment under test. Such a test is in no way conclusive or in accordance with any standards but may highlight a weakness to radiated fields particularly in the 900MHz - 1GHz frequency range.

## *6.4 Proposed Extensions to In-House Test Facilities*

It is proposed to develop a better open area test site near the current facility. This will incorporate a larger ground plane of approximately 10m x 10m which will be permanently installed (rather than rolled out when the need arises. This ground plane will be flatter, have less discontinuities and have a better earth connection. The obstruction free area of this new site is also much larger (approximately 3m square) and overall it is expected that the site attenuation characteristics of this new facility


**Photo 6.15 - Transient surge generator for pre-compliance testing**

will be on a par with compliance test sites. The large local ambient signals will still of course be present.

Also it is hoped to that a low cost, second hand broad band RF power amplifier will be coupled with a suitable signal generator and the existing tuned dipoles to facilitate spot frequency, radiated RF immunity tests to be conducted in the 2m x 2m screened room. This facility should enable susceptibilities identified during compliance testing to be reproduced and hopefully rectified.

# 7. Practical Measurements and Verification

Having established in house testing facilities for making precompliance EMC measurements, the user must then verify the validity of the measurements he or she is able to make. The aim of such verification is to get a level of confidence that compliance indicated by in-house tests will translate to compliance when the equipment is subjected to fully certified compliance tests. The key to EMC testing is repeatability and the first step towards verification is to ensure that the results obtained are repeatable from one test session to the next. The next step is to ensure that in-house results correlate well with measurements made which are traceable to national measurement standards (eg. certified test house results).

In this chapter, some examples of precompliance measurements made on a 1kW, 48VDC-240VAC,50Hz Sine Wave Inverter designed by the author are compared to compliance test house results on the same unit. The inverter used for this test case incorporates three, individual Switch Mode Power Supplies and a supervisory microcontroller and, as such, represents a "high risk" product from an EMC perspective. It should be noted that results presented here are actually the outcome of many test and modification iterations based on in-house emission measurements. Initial prototype tests indicated emissions in excess of 20dB above the allowable limit at some frequencies and a combination of filter optimisation, cable layout, RF earthing and PCB modifications were necessary to achieve the final result.

Also presented in this chapter are some rudimentary "first principle" calibration checks made on the pre-compliance OATS facility.

## *7.1 The EMC Test Plan*

In order to outline what standards and what tests are relevant to a particular product and convey this information to a third party test house, an EMC test plan is essential. This typically sets out the following;

- Description of the equipment and its function
- Objectives and justification for EMC testing
- Standards applied and justification
- Specification of the configuration used and justification
- Details and rationale for the test limits and levels to be applied
- Summary of the compliance and performance levels and the reports required

An example of an EMC test plan for the test case inverter follows;

## EMC Test Plan

**Test Type:** Electro-Magnetic Compatibility

**Model Number:** HPI-3 12/48-240/50I - Serial Number 14462041

**Catalogue Number:** 400335

**Drawing Number:** CR1092xx

**Product Description:**

SINETEC HPI Series **3** 1200VA, 48VDC - 240VAC,50Hz High Performance Sine Wave Inverter with Bypass Facility

**Date:** **12 July, 1996**

**Test Details:**

Aim:

This plan details the test requirements for performing pre-compliance testing in house and prototype compliance testing at a NATA calibrated test house.

EMC testing to harmonised standards is required for CE compliance (Europe) and will be required by the Australian Spectrum Management Authority (SMA) from the beginning of 1997. In addition, compliance with the limits specified in AS/NZS 1044:1995 (CISPR 14) and AS/NZS 3548:1992 (CISPR 22) is required by Telecom Specification 968 Issue 5 and amendments and demonstration of compliance is required by prototype testing.

**Relevant Standards:**

AS/NZS 1044:1995 (CISPR 14 - EN55014):

This standard defines limits and methods of measurement of radio interference emissions in the range 150kHz to 300MHz.

This equipment is apparently covered by the sections of this standard dealing with *"rectifiers, battery chargers and convertors incorporating semiconductor controls"* (clauses 4.1.2.2, 4.1.2.4, 7.2.2, 7.3.7.9). This is contradicted by the fact that stand alone power supplies are specifically excluded from the scope. However the generic emissions standards (AS/NZS 4251.1-1994 and EN 50081-1) call up CISPR 14 and thus conducted emissions tests on all ports would appear to be appropriate.

Clause 4.1.2.4 states that this equipment is not subject to the interference power limits in the range 30MHz to 300MHz. Thus, only conducted (or terminal voltage) interference limits in the frequency range 150kHz to 30MHz as specified in Table I (and measured as per clause 5.2) apply.

Clause 4.2.3.3 states that interference as a result of manual switching operations (eg. ON/OFF) is to be disregarded and hence it is the continuous interference generated by the operation of the inverter that is subject to the specified limits.

Clause 7.2.2 implies that the battery connections (>2m) are to be regarded as additional terminals and interference measurements made with a specified high impedance voltage probe should comply with the appropriate Table I limits (measured at the end of the connection leads when they are bundled to give a 0.8m connection length).

Terminal voltage interference at the mains bypass connection should be conducted using the specified (CISPR 16) artificial mains V-network (ie. a 50Ω/50μH Line Impedance Stabilisation Network or LISN). Measurements should be made at the end of the line cord (bundled to give a connection length of 0.8m).

Load terminal measurements should be made using the specified high impedance probe at the load terminals (ie. at the end of 0.8m connection leads)

The alarm terminals should be treated as additional terminals and thus extended 0.8m and terminated in a typical load (eg. the resistance of a typical 48VDC relay coil, say 4k7). Terminal voltage interference should thus be measured using a high impedance probe.

The Remote Emergency Power Off (REPO) link should also be treated as a additional terminal (0.8m long short circuit loop)

<u>AS 3548:1992 (CISPR22):</u>

This standard has identical requirements for mains terminal conducted emissions and in addition sets limits on radiated emissions up to 1GHz. This standard strictly applies to Information Technology Equipment but the limits are the same as those specified in other standards with Class B type equipment having the most stringent limits. Again this standard is called up in generic emission standards and thus testing to Class B limits is appropriate.

<u>IEC 555 / IEC 1000-3 (Parts 2 and 3):</u>

Although these harmonics and flicker emission standards are called up by the generic emission standards, these would not appear to be applicable to this equipment as the mains connection is essentially only a bypass supply for the load (no significant current is drawn by the unit from the mains supply). A "quick check" verification of this may be in order for compliance testing.

<u>AS/NZS 4251.1 (1994) and EN 50081-1:</u>

These generic emission standards (for residential, commercial and light industry environments) would appear to be the most relevant for this equipment (given the exclusion of stand alone power supplies from CISPR14) and these involve emission measurements in accordance with the standards mentioned above.

AS/NZS 4252.1 (1994) and EN 50082-1 (1992):

These generic immunity standards (for residential, commercial and light industry environments) would appear to be the most relevant for this equipment. Compliance with these standards to performance Criteria B is essential with Performance Criteria A preferred. Additional compliance with the limits set in EN 50082-2 (1992) (for heavy industry) and/or the highest specified level in each of IEC 1000-4-2,3,4,5 to Performance Criteria A would be ideal.

**Pre Compliance Testing:**

EQUIPMENT (for in-house pre compliance testing):

| | |
|---|---|
| LISN: | EMCO model 3825/2; 25A 50ohm, 50/250µH, 10kHz - 100MHz |
| High Impedance probe: | 1500 ohms in series with 22nF on the centre conductor of 50 ohm coax. - gives 30dB attenuation |
| Receiver: | Tektronix Spectrum Analyser Model 2712 (Option 12) 9kHz - 1.8GHz with "CISPR 16" RBW filters |
| Test Site: | Belling-Lee screened room Non-conductive equipment table (0.8m high) positioned 0.4m from the rear wall and 0.8m from the floor mounted LISN |

EUT Configuration:

Inverter DC power was supplied from an EXICOM 48VDC, 50A rectifier in parallel with 4x12V, 6.5AH sealed lead acid batteries (connected in series) via 2m, 6mm$^2$ connection leads bundled to give 0.8m connection length. A typical arrangement employing an earth connection between the positive battery and the protective earth (at the LISN). Bypass mains power taken from the LISN via a 2m IEC cord with excess appropriately bundled. REPO and alarm connections were made using 2m long wires bundled to 0.8m and terminated in a short circuit for the REPO and a nominal 4700ohms between each alarm common and NO and NC terminals. The load was supplied from a rear panel GPO via a 2m line cord to a bank of incandescent light globes where terminal voltage noise measurements were made using the high impedance probe.

The unit was tested under "normal" steady state operation (ie. after the start up initialisation, checking and transfer routine) with the microcontroller running its monitoring loop and performing supervisory operations. Various load conditions were tested and the interference produced was found to be largely independent of loading although slightly worse at 100% load.

**Pre-compliance test results:**

In-house testing revealed that the worst conducted interference produced by the unit was at low frequencies (150kHz - 400kHz) which is linked to harmonics of the power switching frequencies. Compliance by a margin in excess of 6dB was indicated.

**Requirements for Compliance Testing:**

Results are required to demonstrate compliance with the following:

**AS/NZS 4251.1 (1994) and EN 50081-1 (1992)**

AS/NZS 1044 (1995)/CISPR14
conducted emissions on;
Mains port (2 lines - LISN)
DC port (2 lines - voltage probe)
Load port (2 lines - voltage probe)
Alarm port (9 identical lines - voltage probe)
REPO port (1 line - voltage probe)

AS/NZS 3548 (1995)/CISPR22 Class B
conducted emissions on;
Mains port (identical to CISPR 14)
radiated emissions;
at 3m to Class B limits
Verification/check of irrelevance of;
AS 2279./IEC 555/IEC 1000-3-2,3

**AS/NZS 4252.1 (1994) and EN 50082-1 (1992)**

- IEC 1000-4-2 ESD: at least performance criteria B at level 3 (8kV/6kV)
  - Criteria A preferred
  - Criteria A at level 4 (15kV/8kV) ideal
- IEC 1000-4-3 RF: at least performance criteria B at level 2 (3V/m)
  - Criteria A preferred
  - Criteria A at level 3 (10V/m) ideal
- IEC 1000-4-4 EFT: at least performance criteria B at level 2 (1kV/0.5kV)
  - Criteria A preferred
  - Criteria A at level 4 (4kV/2kV) ideal

Additional Standards;
- IEC 1000-4-5 Surges: performance criteria A at level 4

IEC 1000-4-6 Conducted RF: No requirement specified.
IEC 1000-4-11 Voltage interruptions: not relevant (not mains powered)

**Additional Notes for Compliance Testing:**

- Pre-compliance tests indicated that the earthing of the cable screen at the equipment end of the high impedance voltage probe to the screened room/protective earth at the LISN had a marked effect on the readings. If valid, this may be investigated as required.

- Test mains conducted interference with unit in bypass for completeness.

- Remove batteries, rectifier and load from the screened room when doing radiated immunity.

- Test plots required at the completion of tests.

- The unit is designed for rack mounting and thus should be treated as floor standing equipment for earthing (eg. for ESD tests).

- Refer set up photographs for compliance testing of similar units (in test reports).

- Rectifier found to be a significant noise source when doing Class B radiated tests. Will need to run from batteries alone. May need to test at no load to preserve battery life with spot checks at full load to check effect of loading. Turn on rectifier to top up batteries during breaks in testing.

- Generator distortion was found to cause problems with inverter AC input supply sensing and rectifier operation when doing OATS test. EUT should be run from a UPS when testing at the remote OATS.

### *7.2 Conducted Emissions*

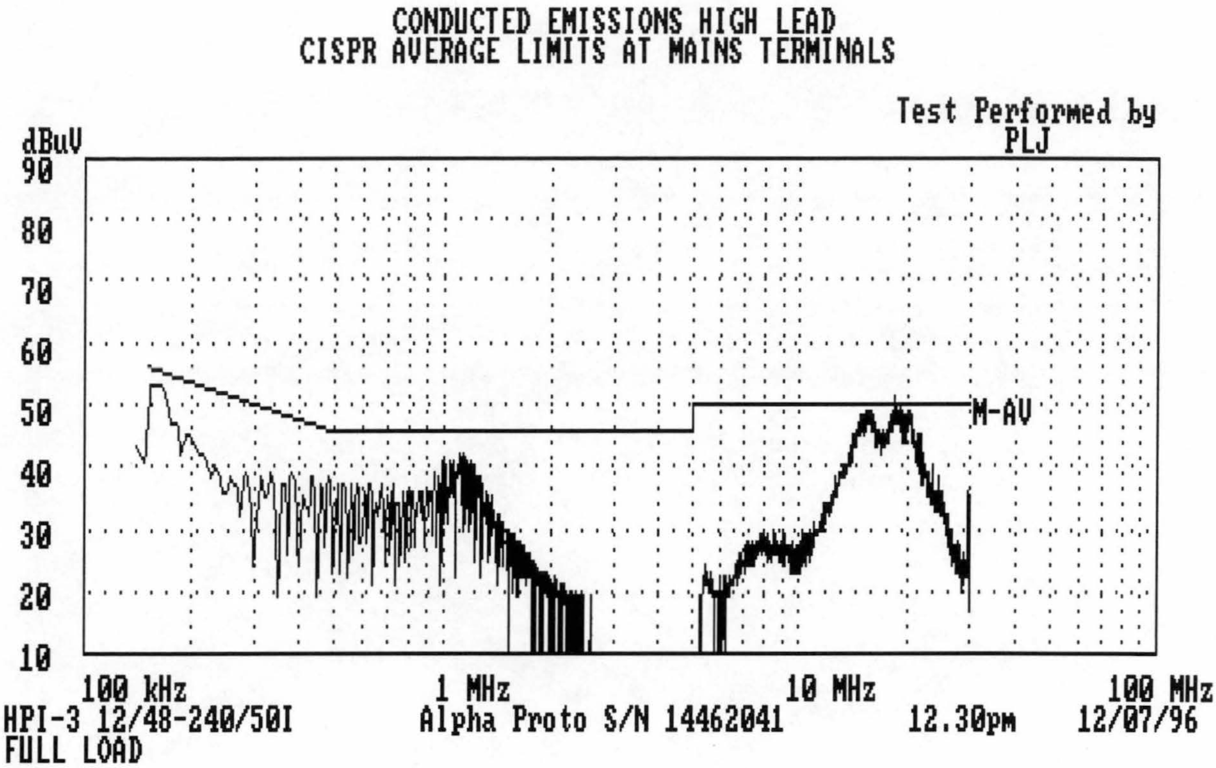
#### *7.2.1 Pre-Compliance*

The results of in-house, pre-compliance, conducted emissions tests on a prototype inverter are shown in graphs 7.2.1 -7.2.8. The unit was set up in the 2m x 2m screened room with cables attached to each port and layed out in accordance with the requirements of the CISPR standards discussed previously. Maximum emission levels were measured when the unit was running full load (as expected) and measurements were made on each port using the appropriate transducer (LISN or High Voltage/High Impedance Probe).

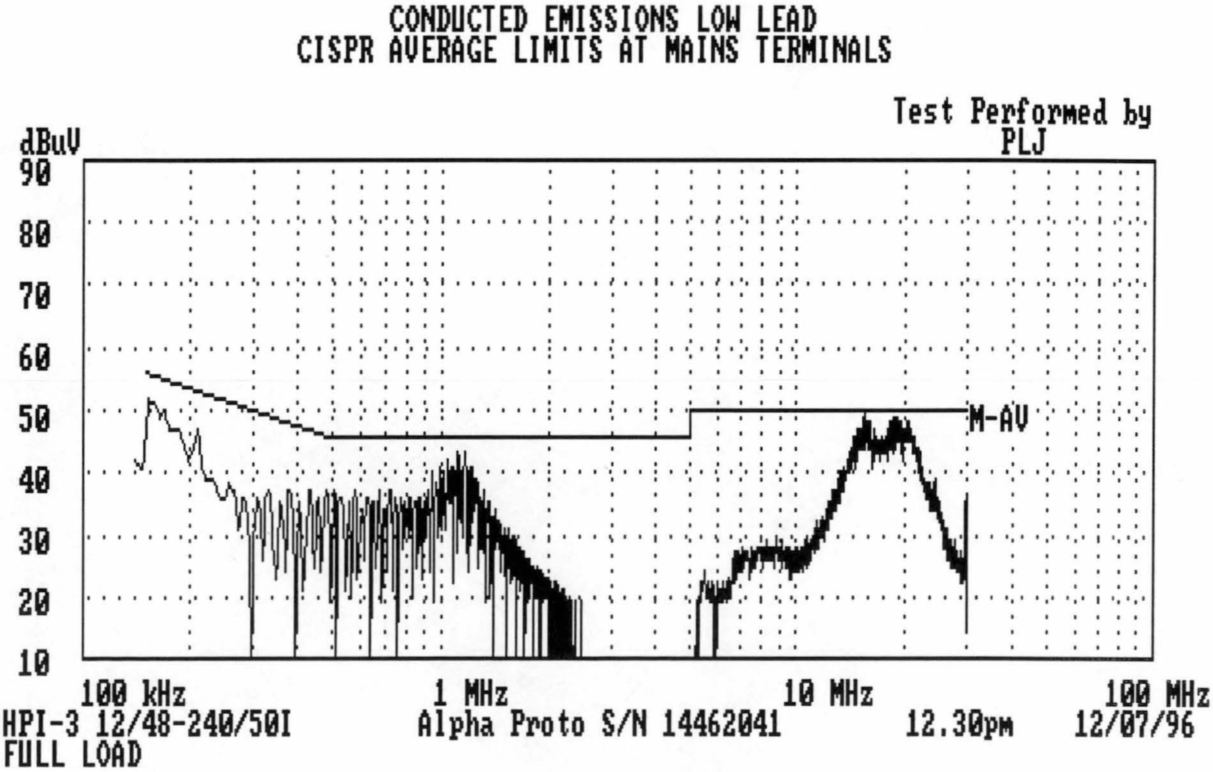
The graphs shown are of the corrected data captured on the controlling notebook computer. That is, the transducer correction factors (attenuations) have been applied to the peak detected results for direct comparison to the limit line. The limit line displayed in each case is the "average" detection limit line which is 10dB below the Quasi-Peak limit line.

The correction factors applied were conservative with 13dB attenuation (flat from 150kHz to 30MHz) assumed for the LISN arrangement. This is comprised of 1±0.5dB for the LISN network (from manufacturers calibration data), 10±0.5dB for the transient limiter and 1dB allowance for cable and connector attenuation. The high impedance probe comprising a 22nF (250VAC Y-grade) coupling capacitor and a 1k5, 1% resistor in series introduces a theoretical attenuation of 29.8dB in a 50Ω measuring system if the impedance of the capacitor is ignored. Insertion loss measurements were performed at spot frequencies between 150kHz and 30MHz and the attenuation of this probe was verified as being reasonably flat at 30dB.

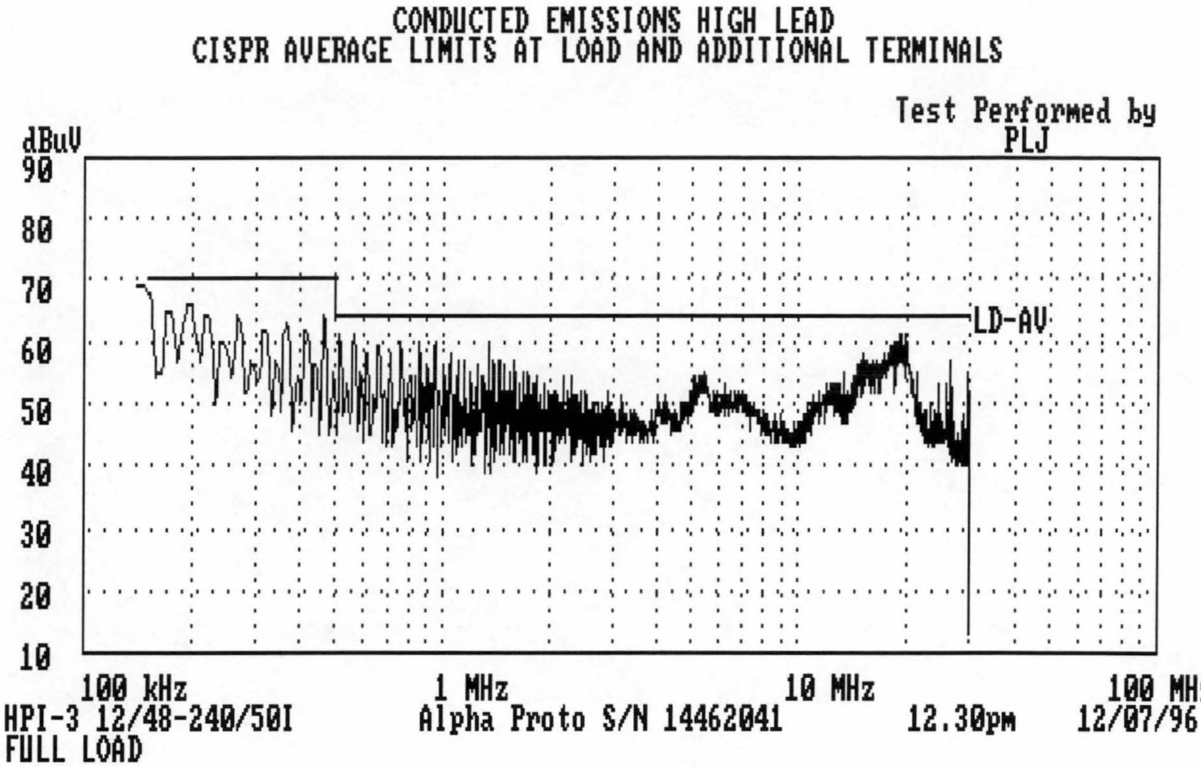
The results shown are really a summary of the pre-compliance conducted emission testing for this product and indicate the final emission levels achieved. Many iterations were involved in investigating the emission profile of this equipment, making design modifications and filter optimisations and retesting to observe the end effect. It should be reiterated that these plots are showing the envelope of the **peak detected** conducted emissions compared against the most stringent **average limits** (10dB below the QP limits). The results obtained indicate no peak detected emissions above the average limit line and this safety margin was deemed adequate to warrant the submission of the product for full compliance testing. The compliance test results are shown in the next section and provide justification for this decision with excellent correlation between the two sets of results and a certified compliance by a comfortable margin.



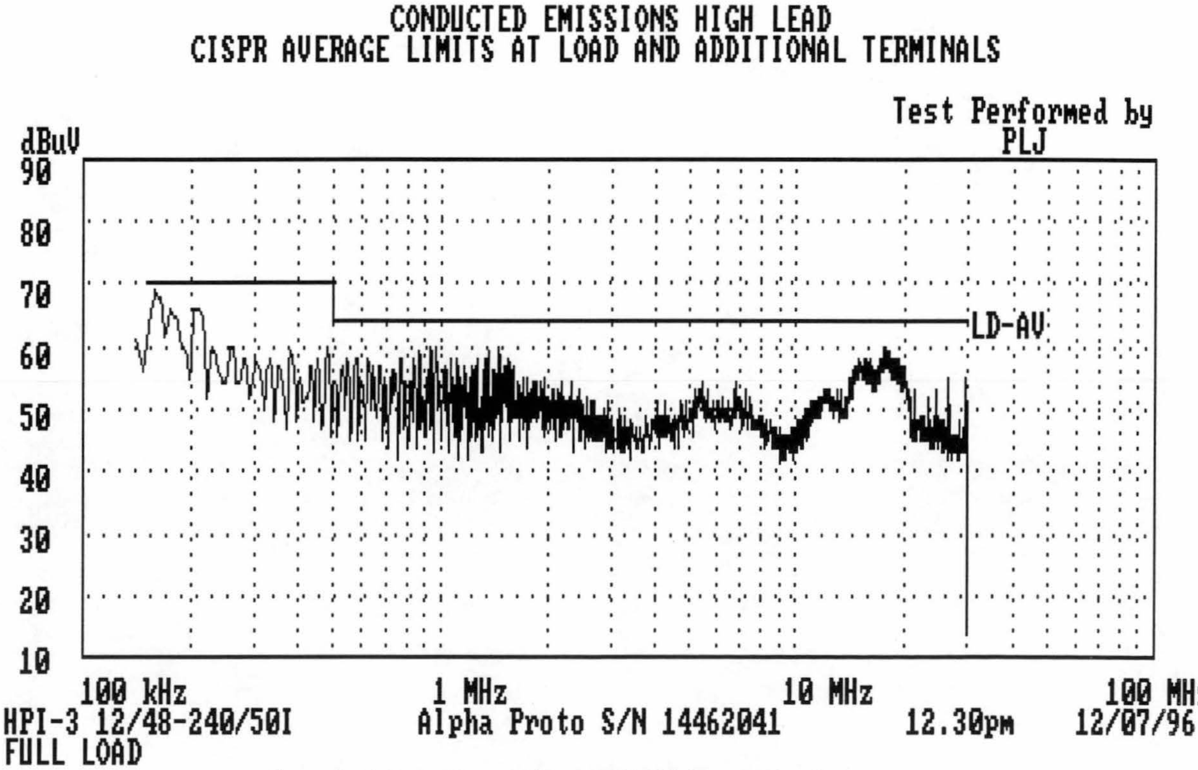

**Graph7.2.1 - Mains High (LISN)**



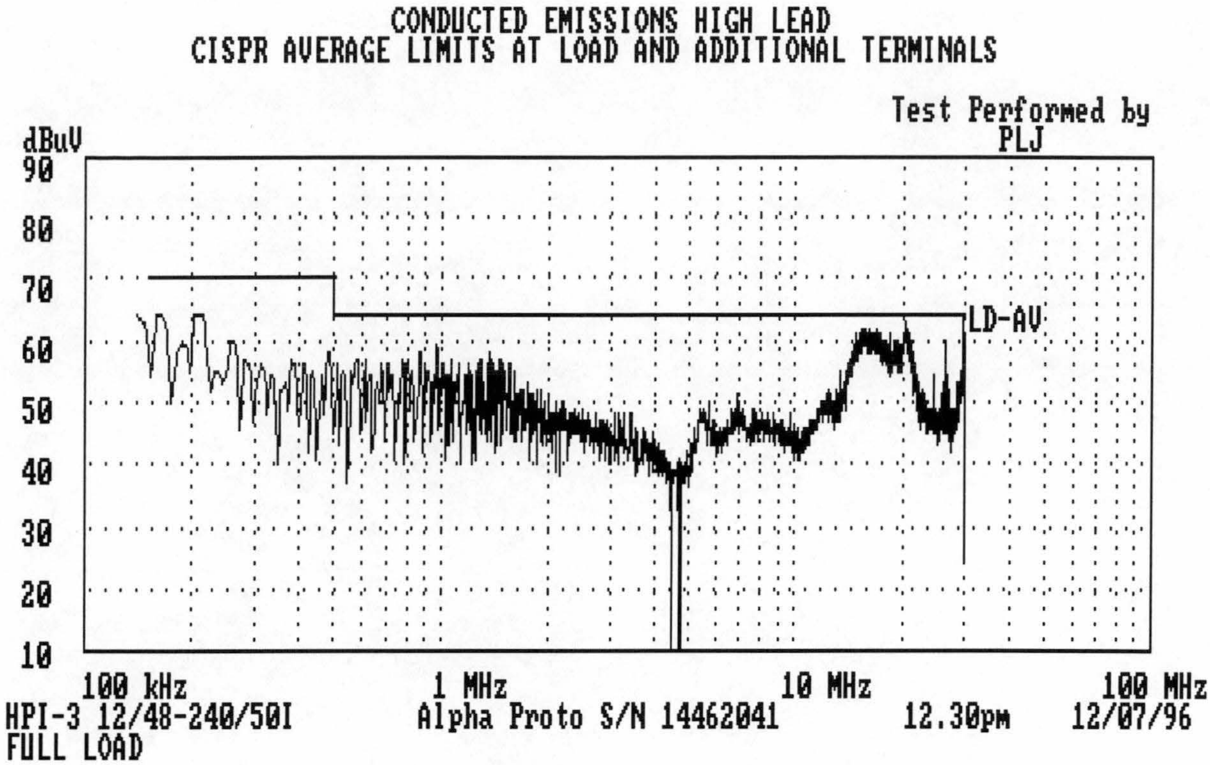

**Graph 7.2.2 - Mains Low (LISN)**



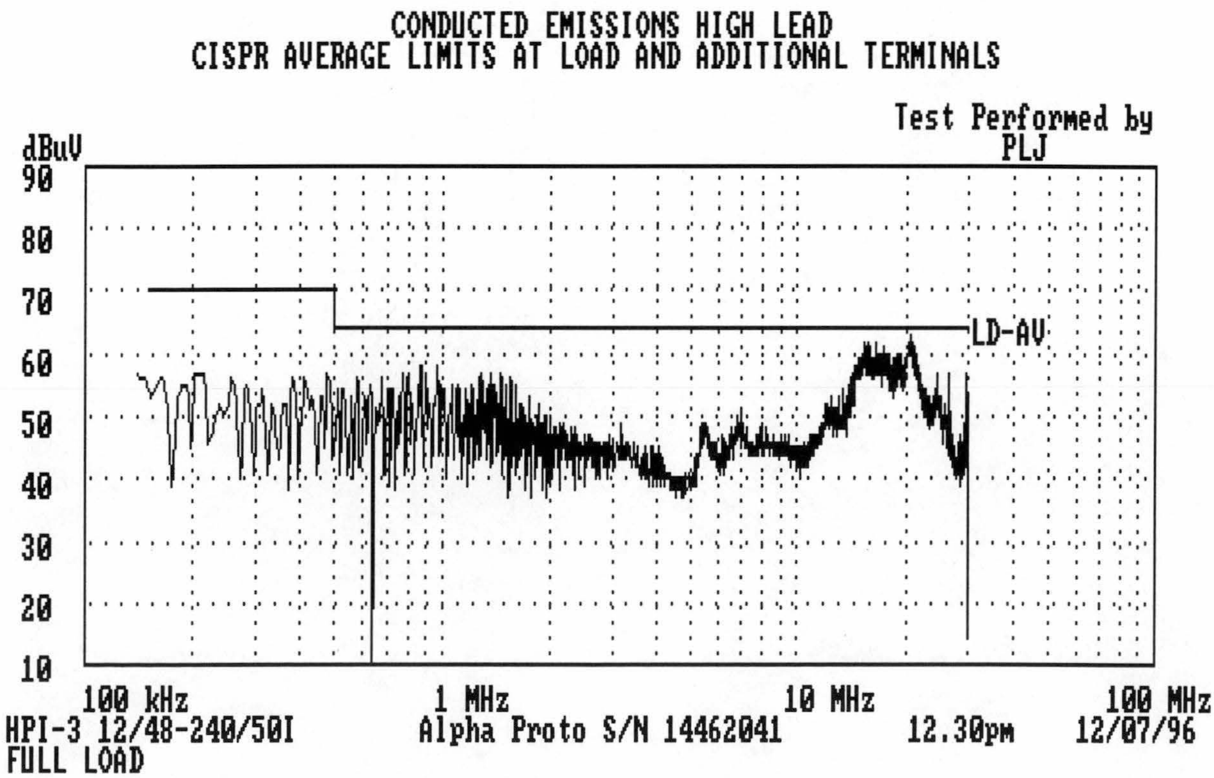

<u>**Graph 7.2.3 - Load Active (Voltage Probe)**</u>



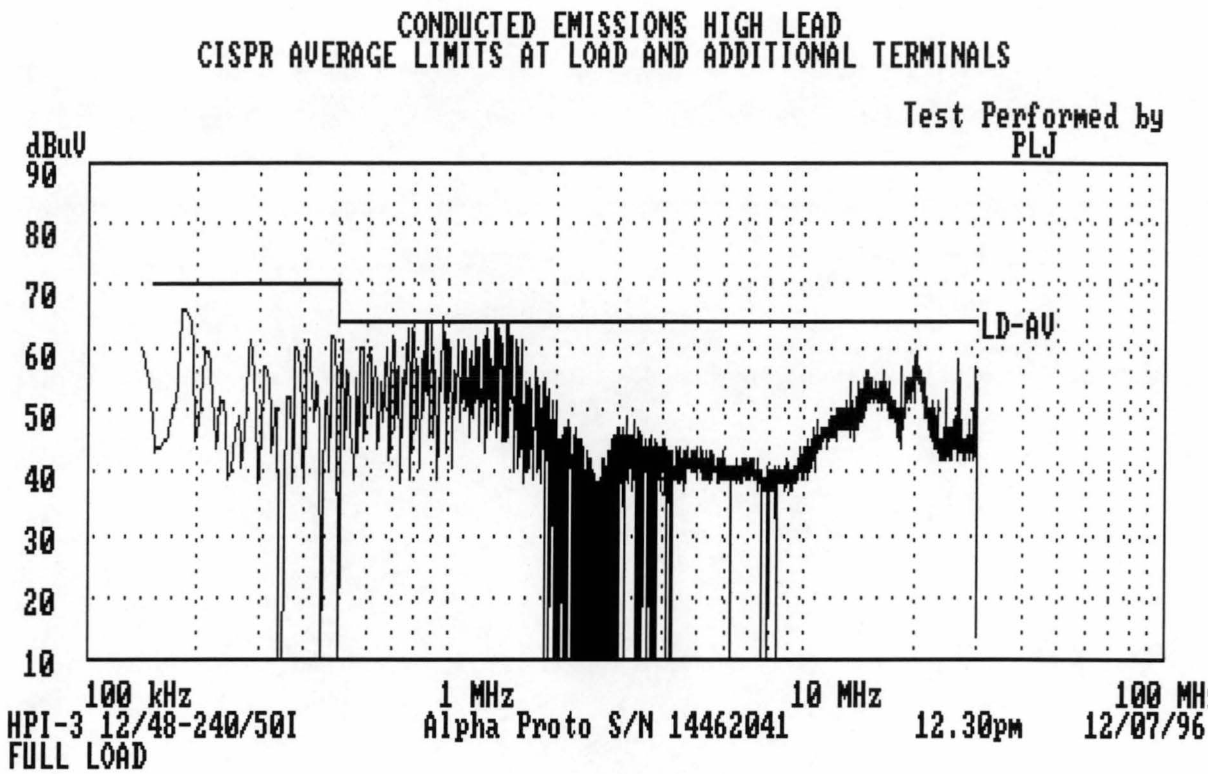

<u>**Graph 7.2.4 - Load Neutral (Voltage Probe)**</u>



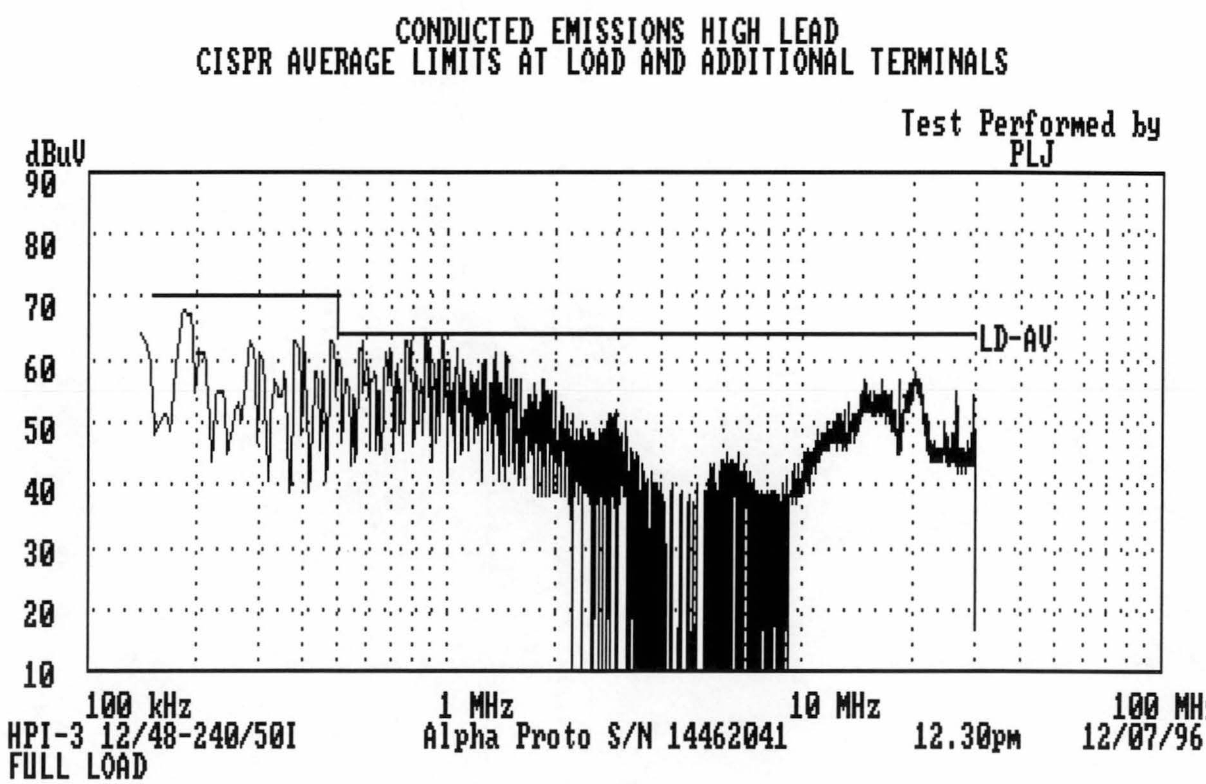

**Graph 7.2.5. - REPO (Voltage Probe)**




**Graph 7.2.6 - Alarm Contacts (Voltage Probe)**




**Graph 7.2.7 - Battery Positive (Voltage Probe)**




**Graph 7.2.8 - Battery Negative (Voltage Probe)**

### *7.2.2 Compliance*

The results of 'identical' certified compliance measurements of conducted emissions on the same inverter unit are shown in c:\pcf\hpi_3.pcf - Graphs 3 - 13 attached.

### *7.2.3 Discussion of Results*

A comparison between identical tests shows excellent correlation between the two sets of results with the emission levels measured "in-house" generally being higher by typically 2-3 dB. The best correlation is seen between results performed using the LISN. For example, the conducted emissions on the mains neutral line (in-house Graph 7.2.2 and compliance test house Graph No. 4). Comparison between these two plots shows very similar measured spectra shapes and levels. A peak just above 1MHz due to a resonance in the mains line filter is identical on both plots and the envelope of the peak low frequency emissions is very similar. There are some deviations in the shape of the peaks measured at higher frequencies but none of these deviations were in excess of 5dB. The deviations in the higher frequency spectra are most likely due to small differences in the cable layout and LISN terminations between the two test set ups and are to be expected.

Measurements made using the high impedance probe also correlate very well. A comparison of the "transducer corrected" measurements made on the Active load terminal for example (in-house Graph 7.2.3 and compliance Graph No. 7) shows correlation of spectra shape and level within a few dB. It should be noted that for measurements made on "load and additional terminals" CISPR 14 specifies the use of the high impedance probe and allows the higher peak and average limits shown. It was found that high impedance probe measurements are generally less repeatable than those made with a LISN and are highly dependent on the earthing arrangement for the coaxial cable to the probe and/or the spectrum analyser input.

The spectra envelopes shown in these plots are typical of the noise produced by Switch Mode Power Supplies with the most problematic frequencies being at the lower end of the frequency range. These low frequency emissions are due to harmonics of the fundamental switching frequencies in the power stages (typically 30 - 60kHz) and substantial filtering is required to reduce these harmonics below the specified limit. The higher frequency peaks are usually due to the "snap off" of power diodes in the switching stages and these tend to be much more broadband in nature.

Closer analysis of the various "automated" measurements indicated on compliance Graph 4 for the 11 highest peaks identified shows the typical relationship between peak, quasi-peak and average measurements for an SMPS emission spectrum. Peak number 5 at 220kHz is due to switching frequency harmonics and has the following peak, quasi peak and average values;

Peak = 44.1dBμV

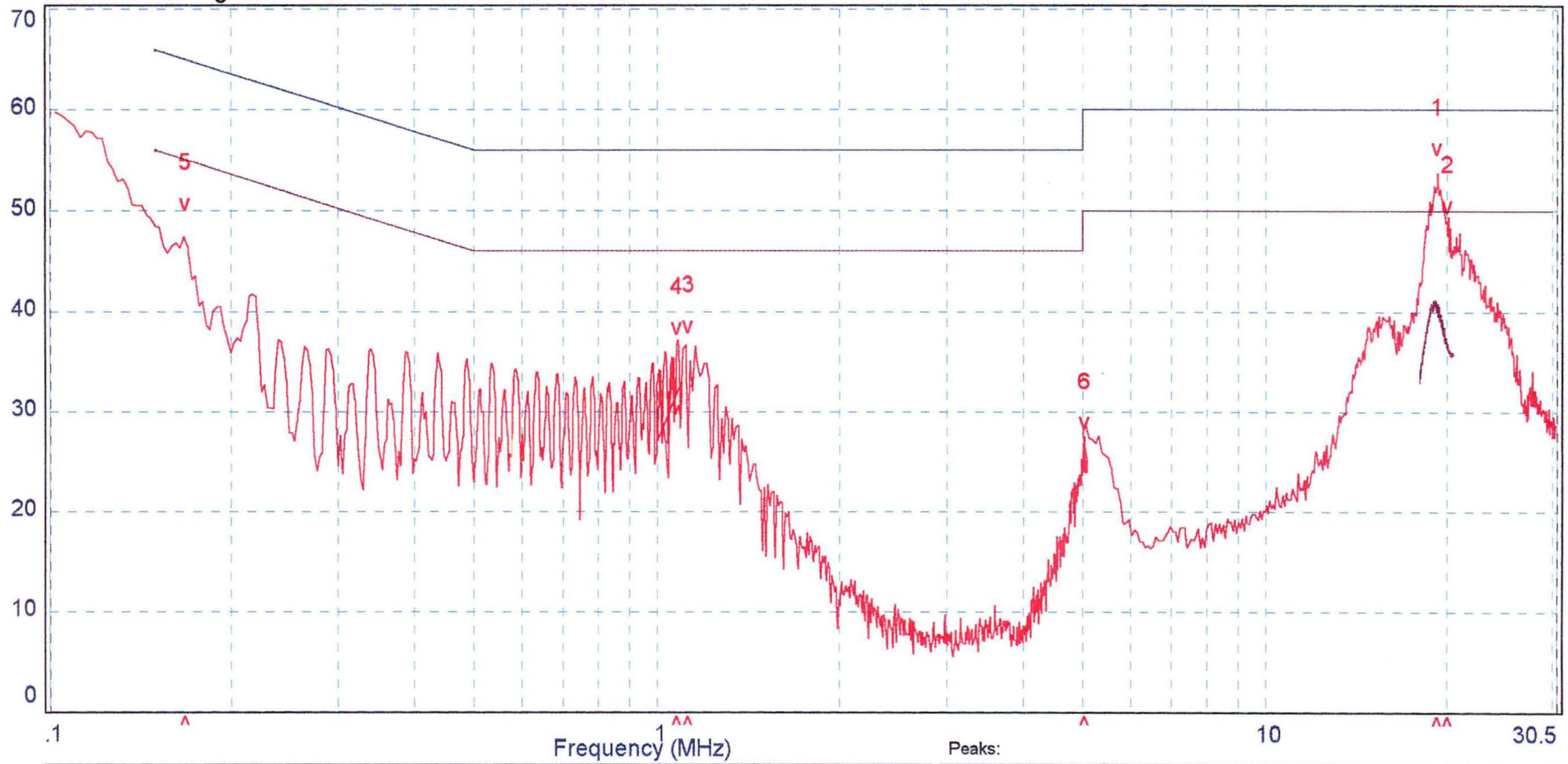
Quasi Peak = 41.8 dBμV

Average = 38.8 dBμV

# EMC Technologies Pty. Ltd. - Global Product Certification

AS3548 Job No:M60732X c:\pcf\hpi_3.pcf

Conducted Voltage dBuV Peak Test Date: 17-07-96 GRAPH No. 3




GLOBAL LIGHTNING TECHNOLOGIES
HPI SERIES-3 INVERTER

ACTIVE LINE

Limits:
3548_BQP AS3548 CONDUCTED CLASS B QP
3548_BAV AS3548 CLASS B CONDUCTED AVERAGE LIMITS

Legend:
Active Line, PEAK TRACE
AVERAGE TRACE

Source:

Equipment:STEVE
Transducers: CABLE_3 LISN c:\m60732x 1 2 3
Site ID: c:\m60732x 9
Test Officer:


Melbourne- 57 Assembly Drv Tullamarine, 3043, Vic, Australia Ph+(613) 9335 3333 Fax+(613) 9338 9260
Sydney---- 16,6 Gladstone Rd Castle Hill, 2154, NSW, Australia Ph+(612) 899 4599 Fax+(612) 899 4019

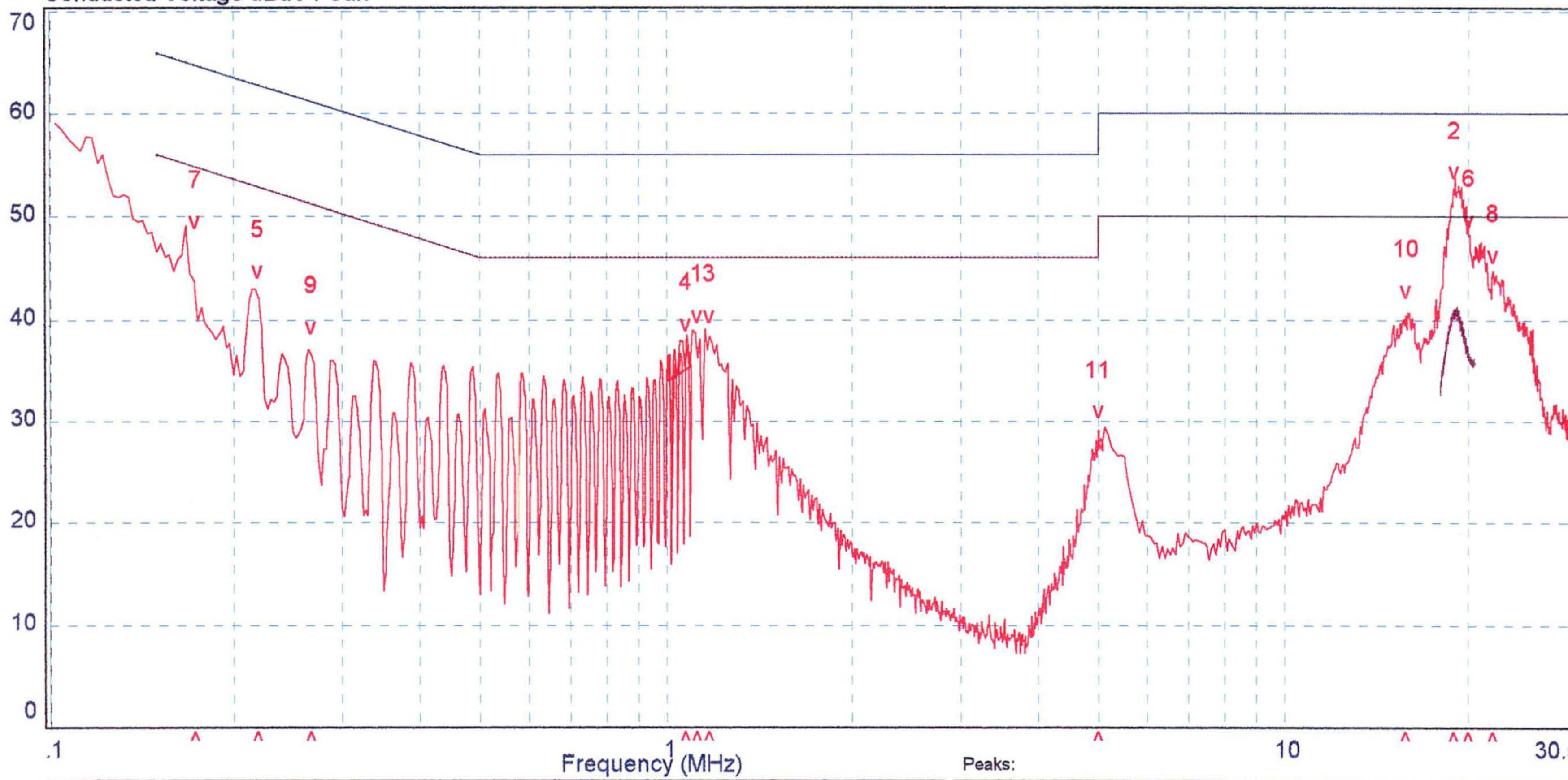

Peaks:

| No | Freq (MHz) | Peak (dBuV) | Qp Val (dBuV) | 3548_BQP (dBuV) | dL1 (dB) | Av Val (dBuV) | 3548_BAV (dBuV) | dL2 (dB) |
|---|---|---|---|---|---|---|---|---|
| 1 | 19.20 | 55.6 | 48.0 | 60.0 | -12.0 | 39.9 | 50.0 | -10.1 |
| 2 | 19.99 | 49.9 | 43.7 | 60.0 | -16.3 | 36.3 | 50.0 | -13.7 |
| 3 | 1.12 | 38.0 | 36.6 | 56.0 | -19.4 | 26.8 | 46.0 | -19.2 |
| 4 | 1.07 | 37.8 | 36.2 | 56.0 | -19.8 | 27.4 | 46.0 | -18.6 |
| 5 | .17 | 50.1 | 41.8 | 65.1 | -23.3 | 34.1 | 55.1 | -21.0 |
| 6 | 5.03 | 28.4 | 25.1 | 60.0 | -34.9 | 18.9 | 50.0 | -31.1 |

# EMC Technologies Pty. Ltd. - Global Product Certification

AS3548 Job No:M60732X c:\pcf\hpi_4.pcf

Conducted Voltage dBuV Peak Test Date: 17-07-96 GRAPH No. 4




GLOBAL LIGHTNING TECHNOLOGIES
HPI SERIES-3 INVERTER

NEUTRAL LINE

Limits:
3548_BQP AS3548 CONDUCTED CLASS B QP
3548_BAV AS3548 CLASS B CONDUCTED AVERAGE LIMITS

Legend:
NEUTRAL LINE, PEAK
AVERAGE TRACE

Source:

Equipment:STEVE
Transducers: CABLE_3 LISN — c:\m60732x 5 6 7
Site ID: — c:\m60732x 8
Test Officer:

Melbourne- 57 Assembly Drv Tullamarine, 3043, Vic, Australia Ph+(613) 9335 3333 Fax+(613) 9338 9260
Sydney---- 16,6 Gladstone Rd Castle Hill, 2154, NSW, Australia Ph+(612) 899 4599 Fax+(612) 899 4019

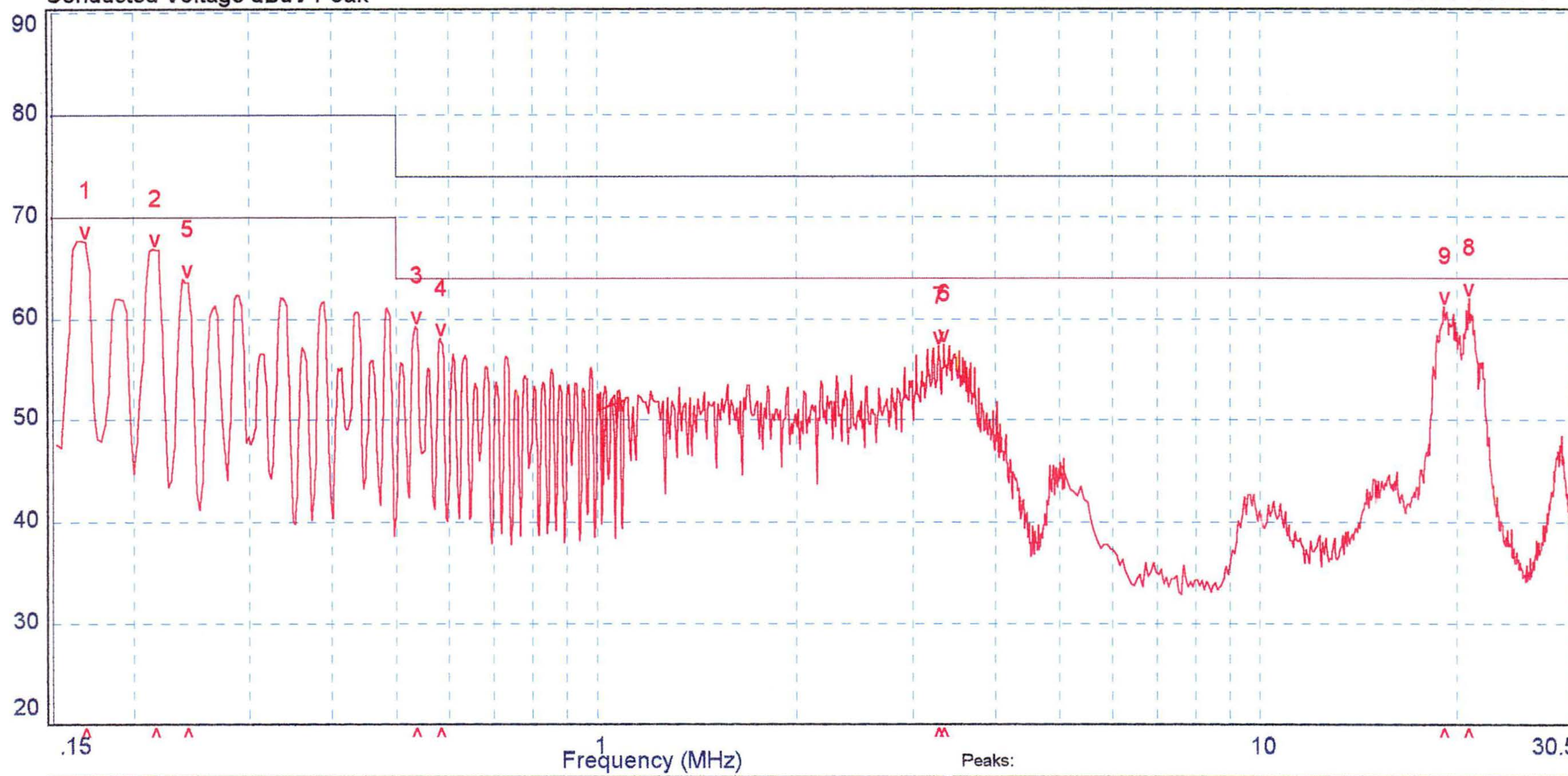
Peaks:

| No | Freq (MHz) | Peak (dBuV) | Qp Val (dBuV) | 3548_BQP (dBuV) | dL1 (dB) | Av Val (dBuV) | 3548_BAV (dBuV) | dL2 (dB) |
|---|---|---|---|---|---|---|---|---|
| 1 | 1.12 | 39.8 | 39.0 | 56.0 | -17.0 | 36.1 | 46.0 | -9.9 |
| 2 | 18.92 | 53.7 | 47.7 | 60.0 | -12.3 | 40.1 | 50.0 | -9.9 |
| 3 | 1.17 | 39.8 | 38.9 | 56.0 | -17.1 | 35.7 | 46.0 | -10.3 |
| 4 | 1.07 | 39.0 | 38.2 | 56.0 | -17.8 | 35.5 | 46.0 | -10.5 |
| 5 | .22 | 44.1 | 41.8 | 62.9 | -21.1 | 38.8 | 52.9 | -14.1 |
| 6 | 19.99 | 49.0 | 42.7 | 60.0 | -17.3 | 35.9 | 50.0 | -14.1 |
| 7 | .17 | 48.9 | 42.9 | 64.8 | -21.9 | 39.8 | 54.8 | -15.0 |
| 8 | 21.92 | 45.6 | 40.8 | 60.0 | -19.2 | 33.2 | 50.0 | -16.8 |
| 9 | .27 | 38.7 | 36.2 | 61.2 | -25.0 | 32.8 | 51.2 | -18.4 |
| 10 | 15.77 | 42.2 | 36.8 | 60.0 | -23.2 | 30.2 | 50.0 | -19.8 |
| 11 | 5.00 | 30.4 | 25.2 | 56.0 | -30.8 | 15.7 | 46.0 | -30.3 |

EMC Technologies Pty. Ltd. - Global Product Certification

AS1044 Job No:M60732X c:\pcf\hpi_7.pcf

Conducted Voltage dBuV Peak Test Date: 17-07-96 GRAPH No. 7




GLOBAL LIGHTNING TECHNOLOGIES
HPI SERIES-3 INVERTER
LOAD TERMINALS
ACTIVE LINE

Limits:
1044_TV3 as1044 TV QP limits - At load & additional terminals.
1044_TV4 as1044 TV AV limits - At load & additional terminals.

Legend:
Active Line, PEAK TRACE

Source:

Equipment:STEVE
Transducers: CABLE_3 HVPROBE c:\m60732x 16 17 18
Site ID:
Test Officer:

Melbourne- 57 Assembly Drv Tullamarine, 3043, Vic, Australia Ph+(613) 9335 3333 Fax+(613) 9338 9260
Sydney--- 16,6 Gladstone Rd Castle Hill, 2154, NSW, Australia Ph+(612) 899 4599 Fax+(612) 899 4019

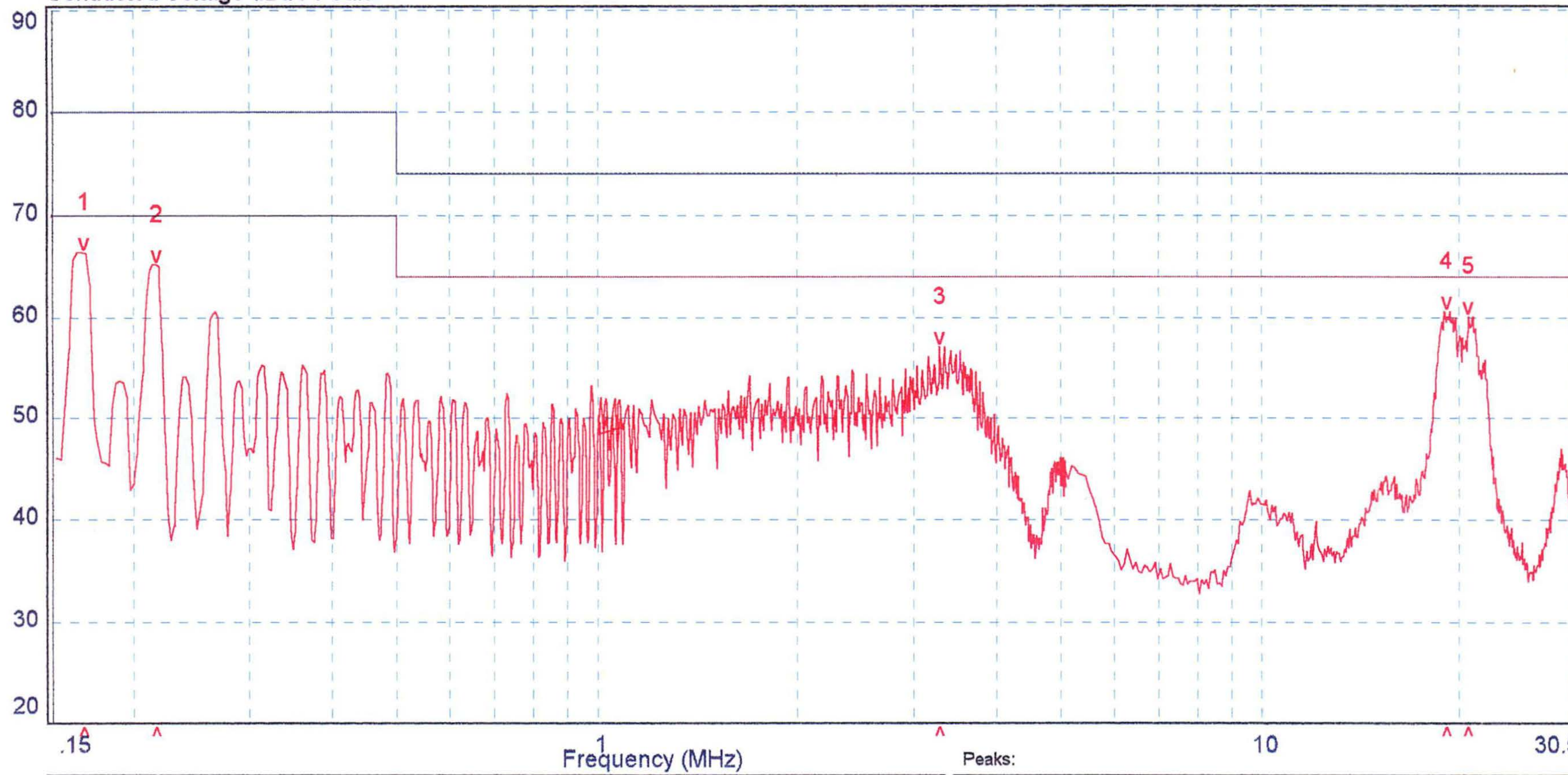
Peaks:

| No | Freq (MHz) | Peak (dBuV) | Qp Val (dBuV) | 1044_TV3 (dBuV) | dL1 (dB) | Av Val (dBuV) | 1044_TV4 (dBuV) | dL2 (dB) |
|---|---|---|---|---|---|---|---|---|
| 1 | .17 | 68.0 | 67.8 | 80.0 | -12.2 | 64.8 | 70.0 | -5.2 |
| 2 | .22 | 67.2 | 66.2 | 80.0 | -13.8 | 63.0 | 70.0 | -7.0 |
| 3 | .54 | 59.6 | 58.8 | 74.0 | -15.2 | 56.8 | 64.0 | -7.2 |
| 4 | .58 | 58.4 | 57.8 | 74.0 | -16.2 | 55.3 | 64.0 | -8.7 |
| 5 | .24 | 64.2 | 62.9 | 80.0 | -17.1 | 59.8 | 70.0 | -10.2 |
| 6 | 3.35 | 57.8 | 54.6 | 74.0 | -19.4 | 50.6 | 64.0 | -13.4 |
| 7 | 3.29 | 57.6 | 55.6 | 74.0 | -18.4 | 49.9 | 64.0 | -14.1 |
| 8 | 20.87 | 62.3 | 57.8 | 74.0 | -16.2 | 49.9 | 64.0 | -14.1 |
| 9 | 19.13 | 61.5 | 57.6 | 74.0 | -16.4 | 49.1 | 64.0 | -14.9 |

EMC Technologies Pty. Ltd. - Global Product Certification

AS1044 Job No:M60732X c:\pcf\hpi_8.pcf

Conducted Voltage dBuV Peak Test Date: 17-07-96 GRAPH No. 8




GLOBAL LIGHTNING TECHNOLOGIES
HPI SERIES-3 INVERTER
LOAD TERMINALS
NEATRAL LINE

Limits:
1044_TV3 as1044 TV QP limits - At load & additional terminals.
1044_TV4 as1044 TV AV limits - At load & additional terminals.

Legend:
__ Neatral Line, PEAK TRACE

Source:
c:\m60732x 19 20 21

Equipment:STEVE
Transducers: CABLE_3 HVPROBE
Site ID:
Test Officer:

Melbourne- 57 Assembly Drv Tullamarine, 3043, Vic, Australia Ph+(613) 9335 3333 Fax+(613) 9338 9260
Sydney---- 16,6 Gladstone Rd Castle Hill, 2154, NSW, Australia Ph+(612) 899 4599 Fax+(612) 899 4019

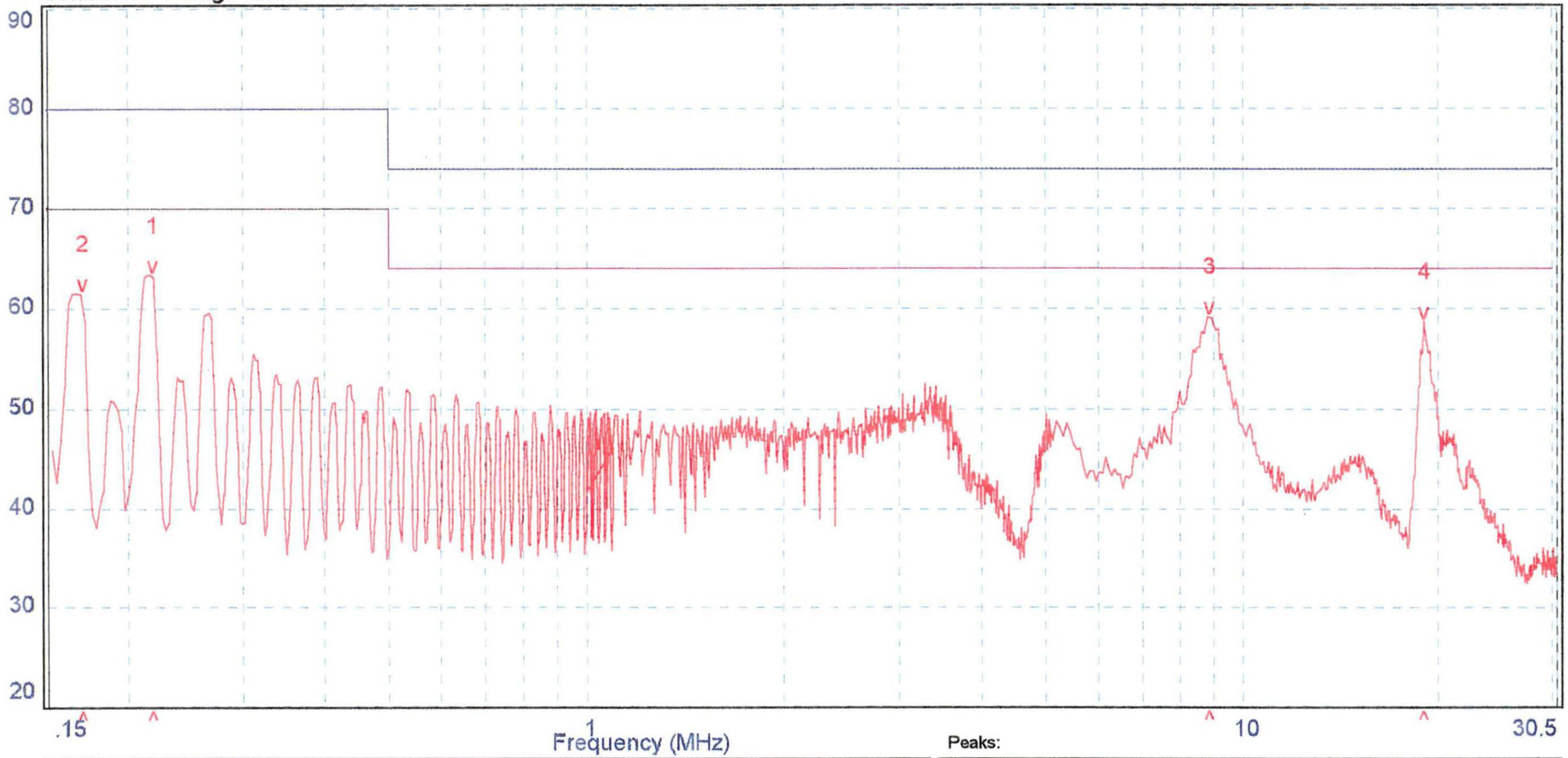
Peaks:

| No | Freq (MHz) | Peak (dBuV) | Qp Val (dBuV) | 1044_TV3 (dBuV) | dL1 (dB) | Av Val (dBuV) | 1044_TV4 (dBuV) | dL2 (dB) |
|---|---|---|---|---|---|---|---|---|
| 1 | .17 | 66.7 | 66.9 | 80.0 | -13.1 | 64.1 | 70.0 | -5.9 |
| 2 | .22 | 65.5 | 65.2 | 80.0 | -14.8 | 62.2 | 70.0 | -7.8 |
| 3 | 3.29 | 57.4 | 55.1 | 74.0 | -18.9 | 49.5 | 64.0 | -14.5 |
| 4 | 19.12 | 60.9 | 56.9 | 74.0 | -17.1 | 49.1 | 64.0 | -14.9 |
| 5 | 20.65 | 60.4 | 56.0 | 74.0 | -18.0 | 48.8 | 64.0 | -15.2 |

EMC Technologies Pty. Ltd. - Global Product Certification

AS1044 Job No:M60732X c:\pcf\hpi_9.pcf

Conducted Voltage dBuV Peak Test Date: 17-07-96 GRAPH No. 9




GLOBAL LIGHTNING TECHNOLOGIES
HPI SERIES-3 INVERTER

REPO LINE

Limits:

1044_TV3 as1044 TV QP limits - At load & additional terminals.
1044_TV4 as1044 TV AV limits - At load & additional terminals.

Legend:

Source:

Equipment:STEVE
Transducers: CABLE_3 HVPROBE
Site ID:
Test Officer:

c:\m60732x 22 23 24

Melbourne- 57 Assembly Drv Tullamarine, 3043, Vic, Australia Ph+(613) 9335 3333 Fax+(613) 9338 9260
Sydney---- 16,6 Gladstone Rd Castle Hill, 2154, NSW, Australia Ph+(612) 899 4599 Fax+(612) 899 4019

Peaks:

| No | Freq (MHz) | Peak (dBuV) | Qp Val (dBuV) | 1044_TV3 (dBuV) | dL1 (dB) | Av Val (dBuV) | 1044_TV4 (dBuV) | dL2 (dB) |
|---|---|---|---|---|---|---|---|---|
| 1 | .22 | 63.6 | 63.4 | 80.0 | -16.6 | 60.7 | 70.0 | -9.3 |
| 2 | .17 | 61.8 | 62.0 | 80.0 | -18.0 | 59.3 | 70.0 | -10.7 |
| 3 | 8.87 | 59.5 | 57.2 | 74.0 | -16.8 | 50.3 | 64.0 | -13.7 |
| 4 | 19.01 | 59.0 | 53.7 | 74.0 | -20.3 | 45.6 | 64.0 | -18.4 |

EMC Technologies Pty. Ltd. - Global Product Certification

AS1044

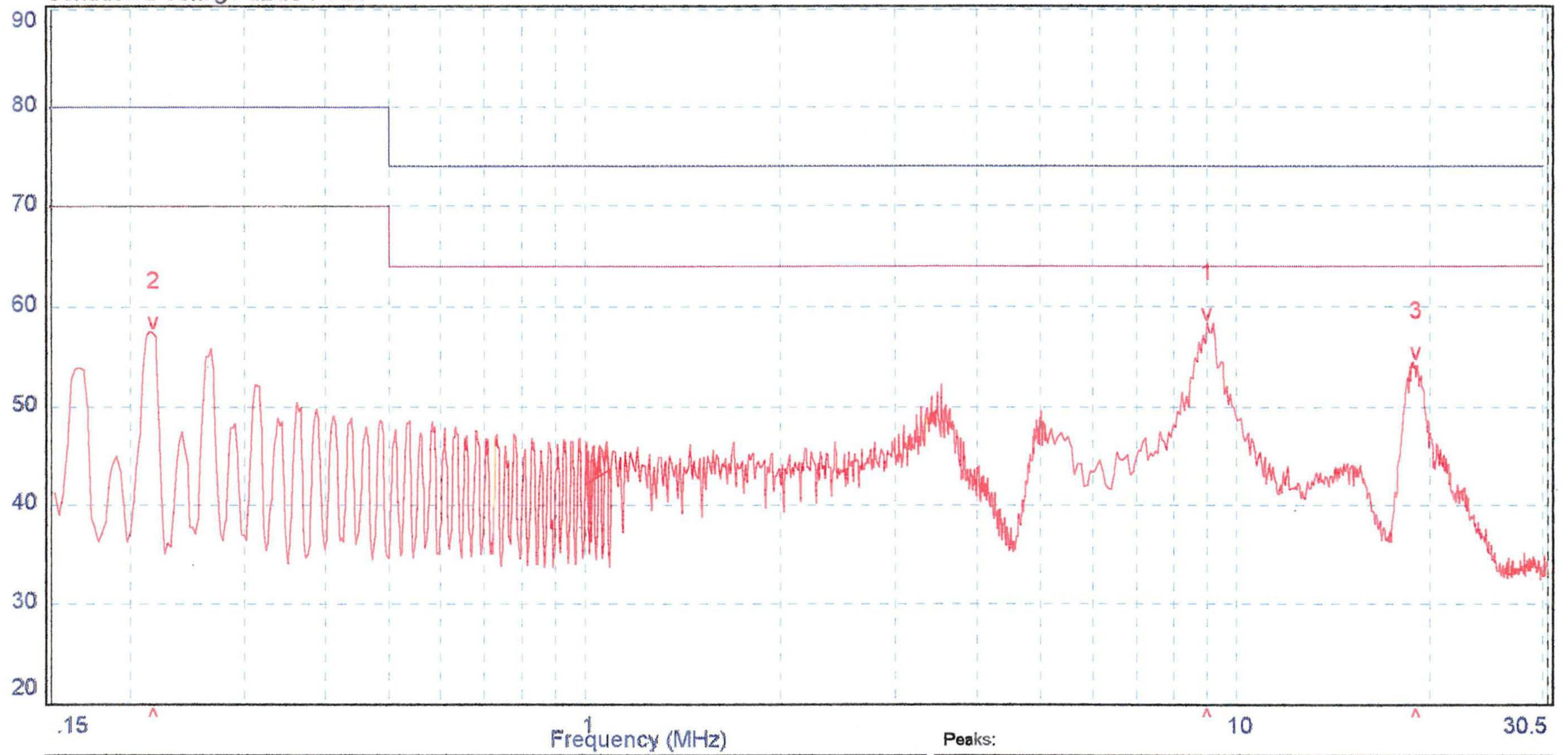
Job No:M60732X

c:\pcf\hpi_12.pcf

Conducted Voltage dBuV Peak

Test Date: 17-07-96

GRAPH No. 12




GLOBAL LIGHTNING TECHNOLOGIES
HPI SERIES-3 INVERTER
EXTENDED ALARM CONTACTS
COMMON

Peaks:

| No | Freq (MHz) | Peak (dBuV) | Qp Val (dBuV) | 1044_TV3 (dBuV) | dL1 (dB) | Av Val (dBuV) | 1044_TV4 (dBuV) | dL2 (dB) |
|---|---|---|---|---|---|---|---|---|
| 1 | 9.00 | 58.7 | 54.5 | 74.0 | -19.5 | 46.0 | 64.0 | -18.0 |
| 2 | .22 | 57.9 | 57.8 | 80.0 | -22.2 | 54.2 | 70.0 | -15.8 |
| 3 | 19.00 | 54.9 | 50.6 | 74.0 | -23.4 | 42.7 | 64.0 | -21.3 |

Limits:

1044_TV3 as1044 TV QP limits - At load & additional terminals.

1044_TV4 as1044 TV AV limits - At load & additional terminals.

Legend:

Source:

Equipment:STEVE

Transducers: CABLE_3 HVPROBE

c:\m60732x 28 29 30

Site ID:

Test Officer:

Melbourne- 57 Assembly Drv Tullamarine, 3043, Vic, Australia Ph+(613) 9335 3333 Fax+(613) 9338 9260
Sydney---- 16,6 Gladstone Rd Castle Hill, 2154, NSW, Australia Ph+(612) 899 4599 Fax+(612) 899 4019

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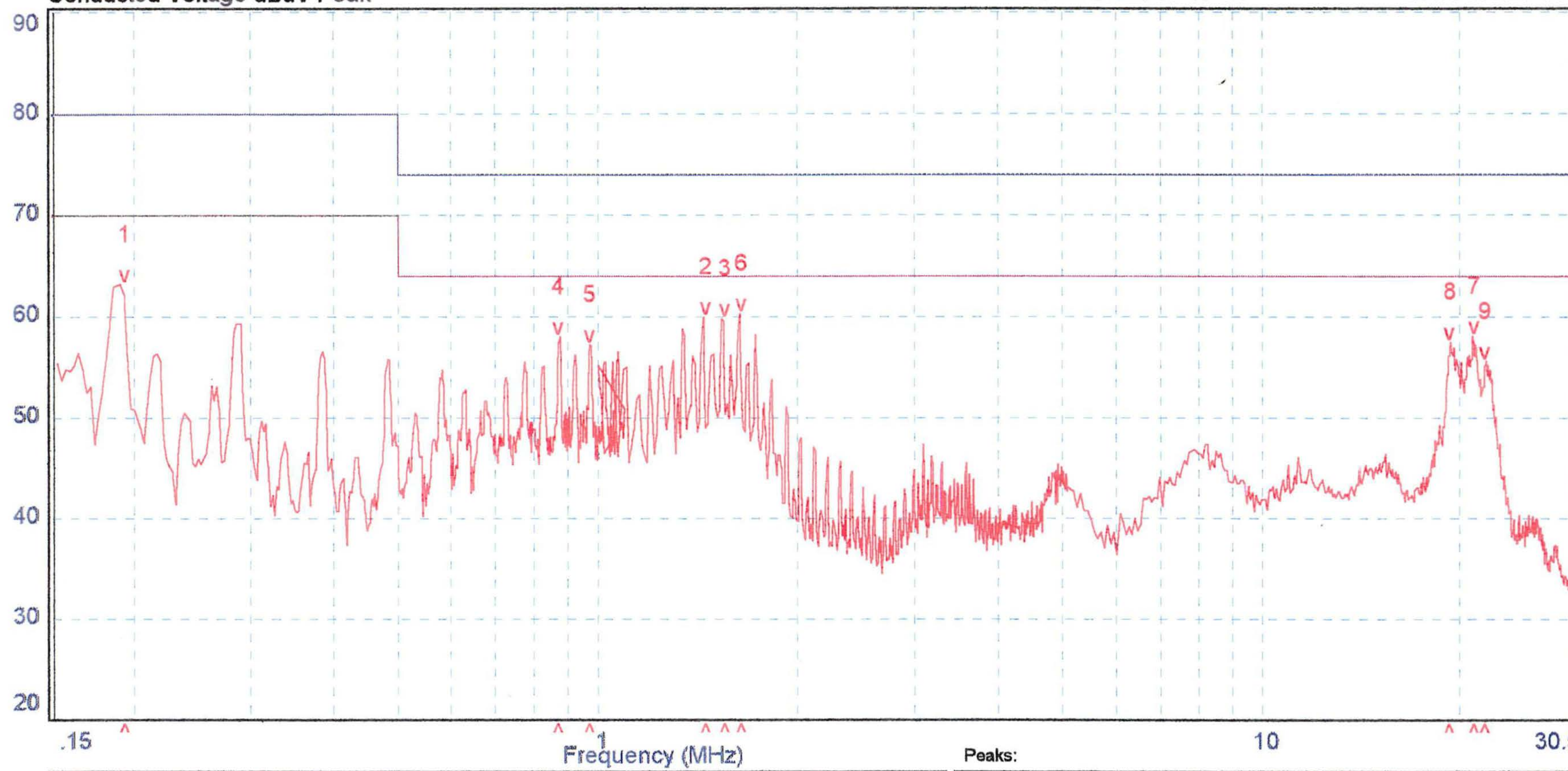
AS1044 Job No:M60732X c:\pcf\hpi_13.pcf

Conducted Voltage dBuV Peak Test Date: 17-07-96 GRAPH No. 13




GLOBAL LIGHTNING TECHNOLOGIES
HPI SERIES-3 INVERTER
BATTERY INPUT LINES
POSITIVE

Limits: Legend:
1044_TV3 as1044 TV QP limits - At load & additional terminals.
1044_TV4 as1044 TV AV limits - At load & additional terminals.

Source:

Equipment:STEVE
Transducers: CABLE_3 HVPROBE c:\m60732x 34 35 36
Site ID:
Test Officer:

Melbourne- 57 Assembly Drv Tullamarine, 3043, Vic, Australia Ph+(613) 9335 3333 Fax+(613) 9338 9260
Sydney---- 16,6 Gladstone Rd Castle Hill, 2154, NSW, Australia Ph+(612) 899 4599 Fax+(612) 899 4019

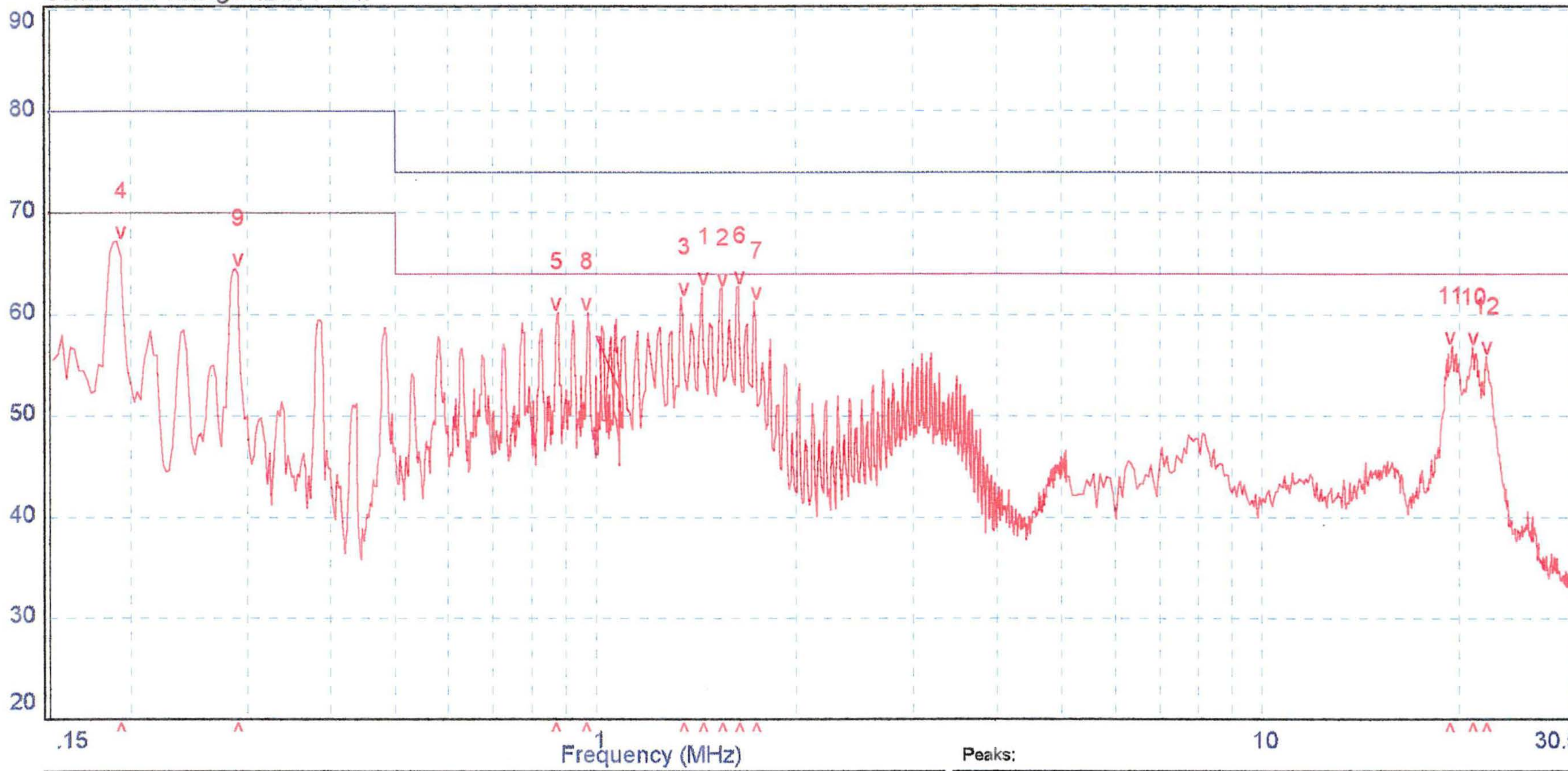
Peaks:

| No | Freq (MHz) | Peak (dBuV) | Qp Val (dBuV) | 1044_TV3 (dBuV) | dL1 (dB) | Av Val (dBuV) | 1044_TV4 (dBuV) | dL2 (dB) |
|---|---|---|---|---|---|---|---|---|
| 1 | .19 | 63.5 | 63.5 | 80.0 | -16.5 | 62.8 | 70.0 | -7.2 |
| 2 | 1.45 | 60.3 | 59.8 | 74.0 | -14.2 | 55.6 | 64.0 | -8.4 |
| 3 | 1.55 | 60.1 | 59.3 | 74.0 | -14.7 | 55.3 | 64.0 | -8.7 |
| 4 | .87 | 58.3 | 57.4 | 74.0 | -16.6 | 55.0 | 64.0 | -9.0 |
| 5 | .97 | 57.5 | 56.7 | 74.0 | -17.3 | 54.3 | 64.0 | -9.7 |
| 6 | 1.64 | 60.6 | 59.3 | 74.0 | -14.7 | 53.9 | 64.0 | -10.1 |
| 7 | 21.02 | 58.4 | 52.7 | 74.0 | -21.3 | 45.4 | 64.0 | -18.6 |
| 8 | 19.28 | 57.8 | 53.1 | 74.0 | -20.9 | 45.3 | 64.0 | -18.7 |
| 9 | 21.84 | 55.9 | 52.5 | 74.0 | -21.5 | 44.4 | 64.0 | -19.6 |

EMC Technologies Pty. Ltd. - Global Product Certification

AS1044 Job No:M60732X c:\pcf\hpi_14.pcf

Conducted Voltage dBuV Peak Test Date: 17-07-96 GRAPH No. 14




GLOBAL LIGHTNING TECHNOLOGIES
HPI SERIES-3 INVERTER
BATTERY INPUT LINES
NEGATIVE

Limits:
1044_TV3 as1044 TV QP limits - At load & additional terminals.
1044_TV4 as1044 TV AV limits - At load & additional terminals.

Legend:

Source:

Equipment:STEVE
Transducers: CABLE_3 HVPROBE
c:\m60732x 37 38 39
Site ID:
Test Officer:

Melbourne- 57 Assembly Drv Tullamarine, 3043, Vic, Australia Ph+(613) 9335 3333 Fax+(613) 9338 9260
Sydney---- 16,6 Gladstone Rd Castle Hill, 2154, NSW, Australia Ph+(612) 899 4599 Fax+(612) 899 4019

Peaks:

| No | Freq (MHz) | Peak (dBuV) | Qp Val (dBuV) | 1044_TV3 (dBuV) | dL1 (dB) | Av Val (dBuV) | 1044_TV4 (dBuV) | dL2 (dB) |
|---|---|---|---|---|---|---|---|---|
| 1 | 1.45 | 63.0 | 62.5 | 74.0 | -11.5 | 59.1 | 64.0 | -4.9 |
| 2 | 1.55 | 62.9 | 62.3 | 74.0 | -11.7 | 58.8 | 64.0 | -5.2 |
| 3 | 1.35 | 62.0 | 61.5 | 74.0 | -12.5 | 58.6 | 64.0 | -5.4 |
| 4 | .19 | 67.5 | 66.6 | 80.0 | -13.4 | 64.6 | 70.0 | -5.4 |
| 5 | .87 | 60.5 | 59.5 | 74.0 | -14.5 | 57.7 | 64.0 | -6.3 |
| 6 | 1.64 | 63.1 | 62.2 | 74.0 | -11.8 | 57.5 | 64.0 | -6.5 |
| 7 | 1.74 | 61.6 | 60.9 | 74.0 | -13.1 | 57.1 | 64.0 | -6.9 |
| 8 | .97 | 60.5 | 59.0 | 74.0 | -15.0 | 57.0 | 64.0 | -7.0 |
| 9 | .29 | 64.8 | 63.7 | 80.0 | -16.3 | 61.8 | 70.0 | -8.2 |
| 10 | 21.00 | 57.1 | 52.4 | 74.0 | -21.6 | 45.0 | 64.0 | -19.0 |
| 11 | 19.35 | 57.2 | 51.9 | 74.0 | -22.1 | 43.9 | 64.0 | -20.1 |
| 12 | 22.01 | 56.2 | 51.3 | 74.0 | -22.7 | 43.9 | 64.0 | -20.1 |

This is typical of these narrower band peaks at low frequency with usually a 4-6dB drop expected between peak and average values. A similar average value was measured using the in-house spectrum analyser with a 3Hz video band width applied (centre frequency = 220kHz, 10kHz/div, RBW=9kHz and maximum sweep time for calibrated measurement). Knowing the typical peak to average drop is useful knowledge when assessing peak measurements that are above or on the average limit line.

The broader band peak at 19 MHz (peak number 2) displays a much greater deviation between peak, QP and average detected levels;

Peak = 53.7dBμV

Quasi Peak = 47.7dBμV

Average = 40.1dBμV

The small section of purple trace around this frequency represents a plot of the average emission levels over this limited frequency range and the large drop from the peak trace shows compliance with the average limits by more than 9dB. This technique of performing a peak trace and only invoking QP and average measurements when the peak is near or above the appropriate limit line enables the complete test to be performed in the least amount of time.

### *7.3 Radiated Emissions*

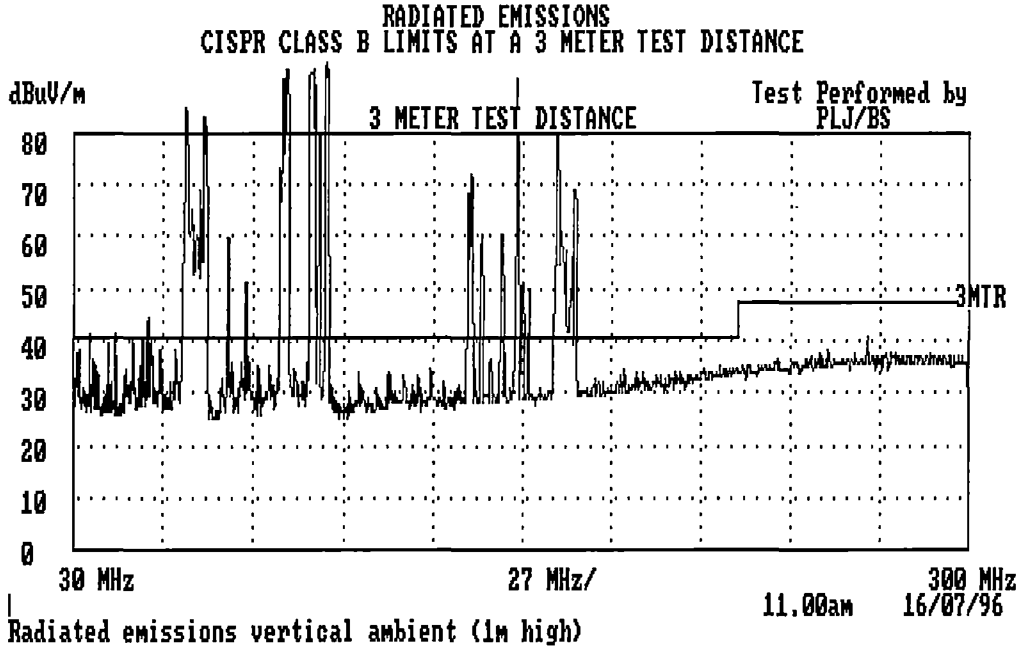
#### *7.3.1 Pre-Compliance*

Graphs 7.3.1 and 7.3.2 show typical plots of vertical and horizontally polarised ambient radiated emissions in the frequency range (30MHz - 300MHz) for the pre-compliance OATS described previously.

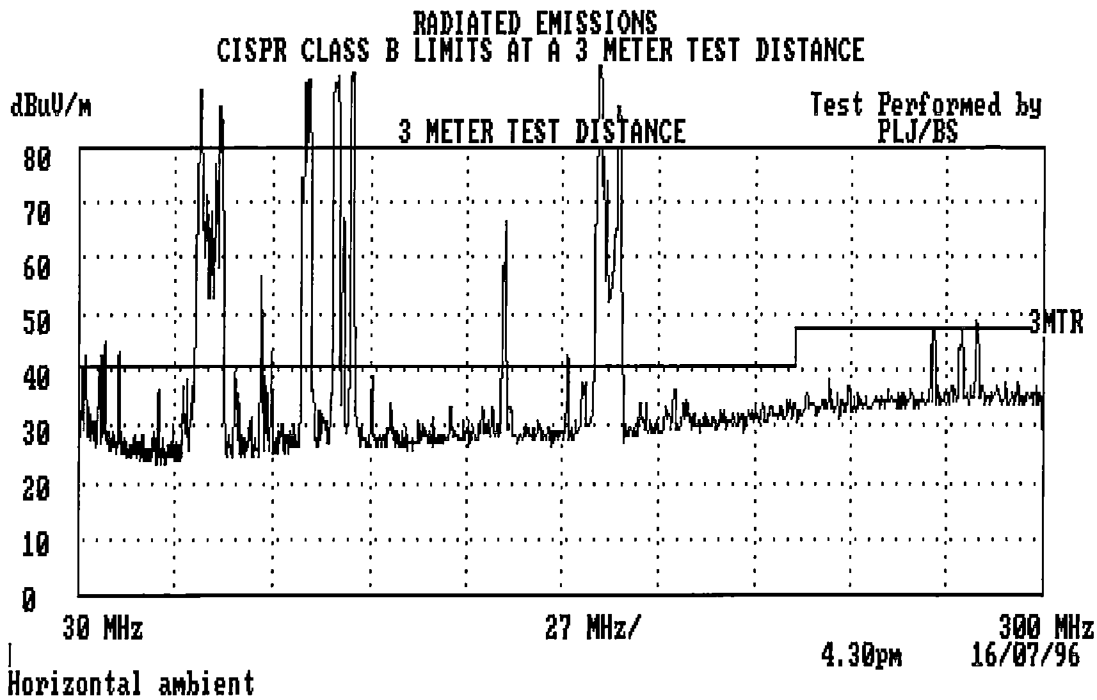
The graphs shown are of the corrected data captured on the controlling notebook computer. That is, the transducer correction factors (in this case the antenna factors and cable loss attenuation factors) have been applied to the peak detected results for direct comparison to the limit line. The limit line displayed in each case is the most stringent CISPR Quasi Peak detection limit line for Class B equipment (for unrestricted use) which is 10dB below the Quasi-Peak limit line for Class A equipment (which may only be used in industrial environments). The antenna used in this frequency band is the biconical antenna described previously and the measurement RBW is 120kHz as required by the CISPR standards.

Graph 7.3.3 is an ambient trace of the frequency range (300MHz - 1GHz) made using the circularly polarised conical log spiral antenna described previously. The manufacturer supplied circular polarisation antenna factors have been applied to the data for this plot. This type of antenna exhibits a 3dB relative attenuation to either horizontal or vertical polarisations and this correction factor has not been applied to the plotted data. This would account for the small step change in received signal level between the plots for Band C (with the biconical antenna) and the plot for Band D (with the circularly polarised log spiral antenna).

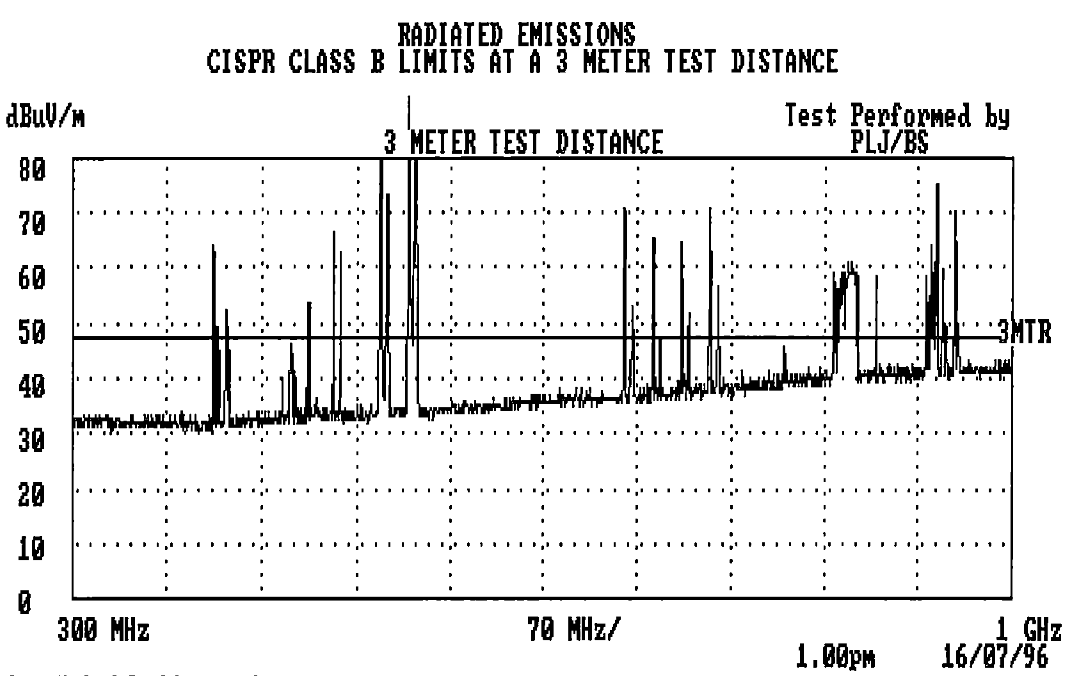
These ambient traces show clearly the major problem with performing pre-compliance radiated emission tests on an OATS which is not remote from civilisation. The general noise floor is typically only 10dB below the Class B limits at a 3m test distance and the proportion of the spectrum swamped by high level broadcast signals is significant. Most of these high ambient signals were identified using the zero span and the audio output demodulating features of the spectrum analyser. The high level signals in the 60-70MHz region are related to Channel 2 (ABC) television transmission, the various FM broadcast stations are identifiable in the 90 -110MHz band and other UHF communication and television services account for most of the higher frequency ambients encountered in band C. The most notable ambients in Band D are the Advanced Mobile Phone System (AMPS) signals (analogue mobile phones using FM) identifiable in the 800 - 900MHz region and the more "secure" GSM digital mobile phone signals above 900MHz.




**Graph 7.3.1 - Ambients: Vertical Polarisation (30MHz - 300MHz)**




**Graph 7.3.2 - Ambients: Horizontal Polarisation (30MHz - 300MHz)**




**Graph 7.3.3 Ambients: Circularly Polarised Log Spiral (300MHz - 1GHz)**

The pre-compliance radiated emission measurements made on the test case inverter are shown in Graphs 7.3.4, 7.3.5 and 7.3.6. As for the ambient measurements, these are plots of corrected data compared to the 3m CISPR Class B limit line.

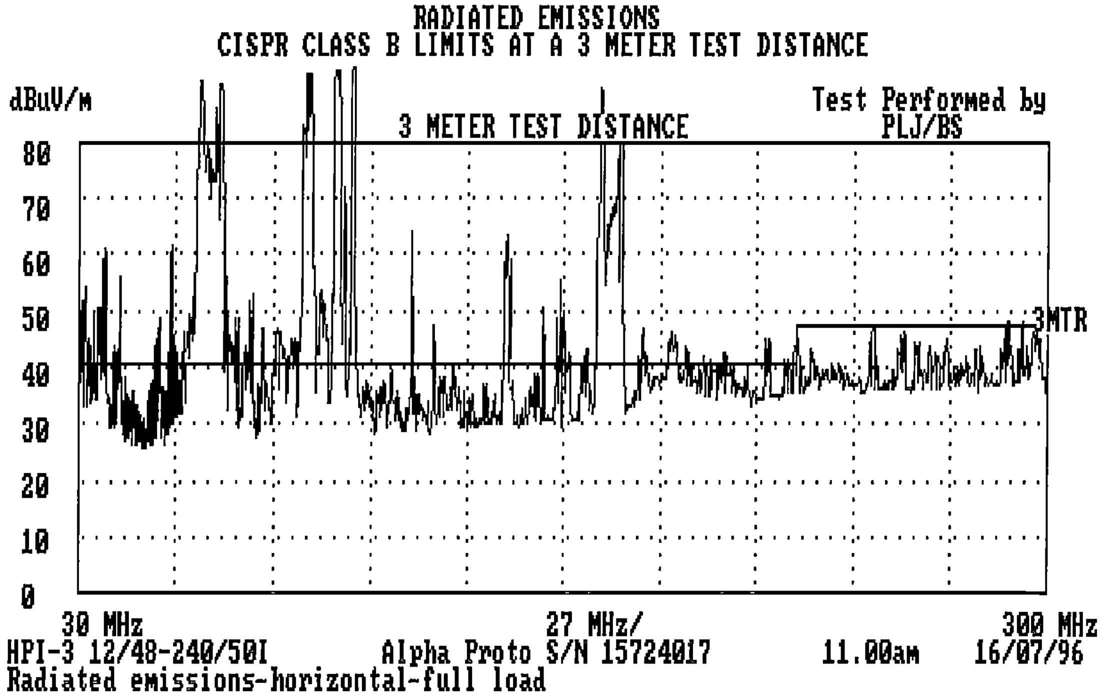



**Figure 7.3.4 - Horizontally polarised radiated emissions scan (30MHz - 300MHz)**

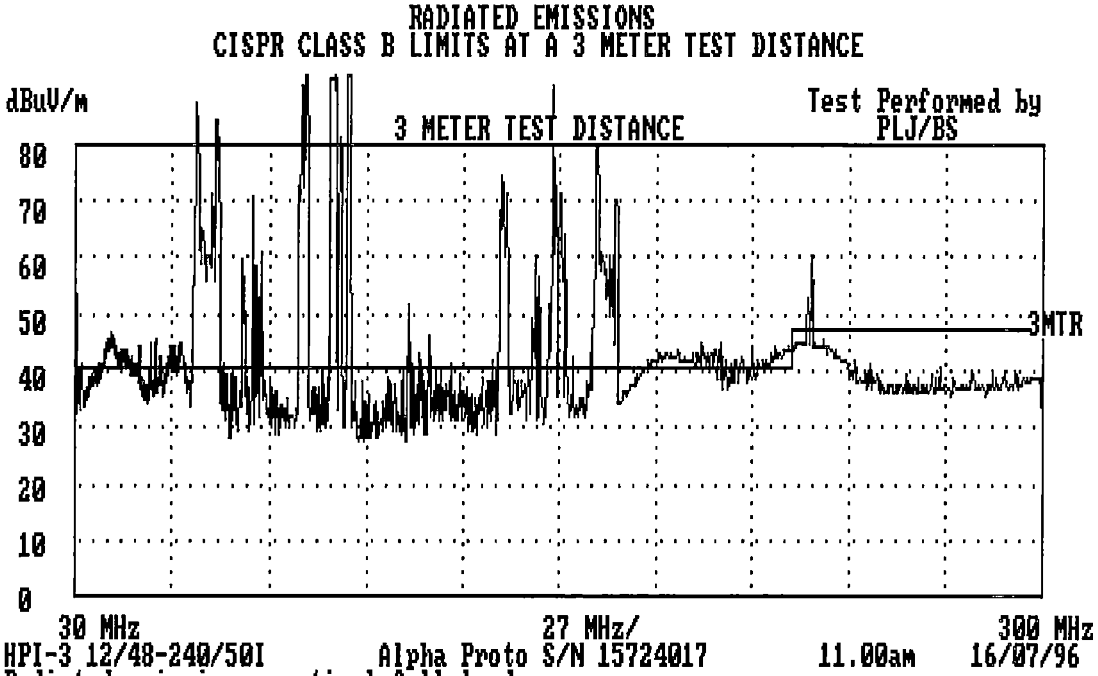



**Figure 7.3.5 - Vertically polarised radiated emissions scan (30MHz - 300MHz)**

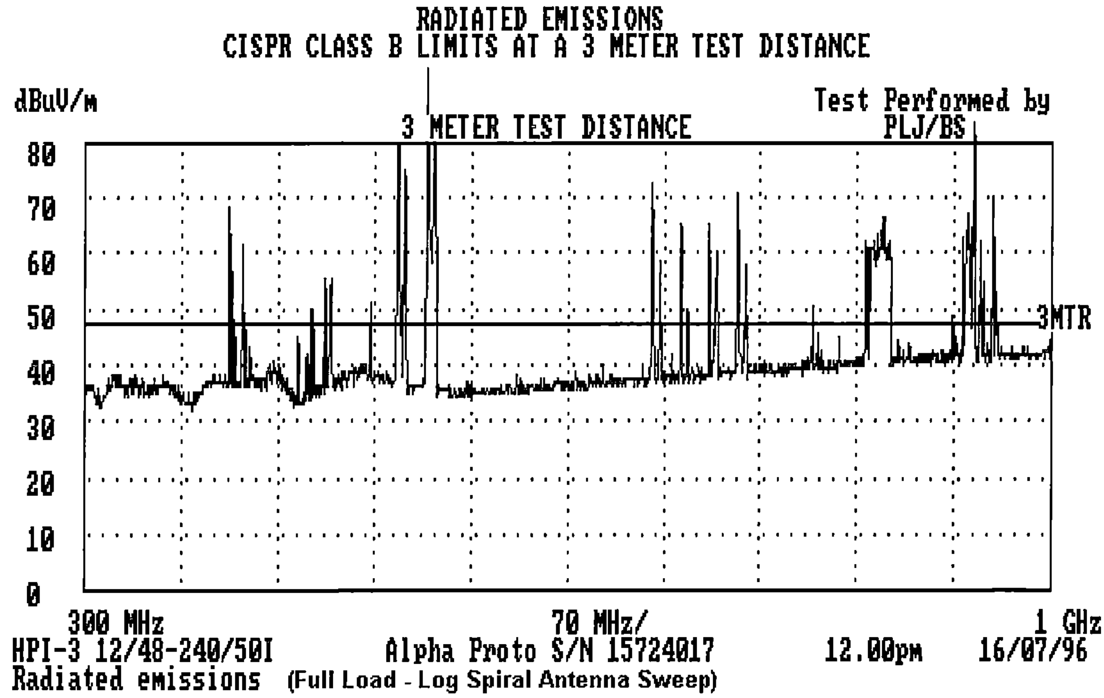



**Figure 7.3.6 - Radiated emissions scan (300MHz - 1GHz): circular polarisation**

### *7.3.2 Compliance*

The results of a vertically polarised emission scan (30MHz - 300MHz) at a compliance OATS with the inverter running at half load is shown in c:\pcf\CRITE_1.PCF Graph No. 1 attached.

Also attached are complete compliance scans for a different inverter product obtained earlier at the same OATS facility (C:\CRIT_1.PCF GRAPH No. 1 and C:\CRIT_2.PCF GRAPH No. 2).

### *7.3.3 Discussion of Results*

The first contrast worthy of note is the difference between the ambient levels measured at the compliance "remote" OATS (shown in green on the plots) and the ambients measured on the pre-compliance OATS. Clearly the general "noise floor" is more than 10dB lower at the remote compliance OATS and even though there are ambient signals present above the limit line, the peak amplitude of these is typically 30dB lower than the very strong levels received (generally from the Mount Wellington transmitter) on the pre-compliance "car park" OATS. The ambient profile at the compliance OATS is very well known and each of these ambient signals is "tagged" and disregarded during testing. In addition, "pre-scans" of the EUT emission profile are conducted in a screened room to ensure that there is no narrowband emissions likely to be masked by any of the ambients at the OATS.

An analysis of the equipment emissions measured is very instructive. Consider first the complete scan compliance plots for vertically and horizontally polarised emissions (C:\CRIT_1.PCF and C:\CRIT_2.PCF) for an earlier inverter product. Note that these plots are the concatenation of Band C and Band D measurements made with two

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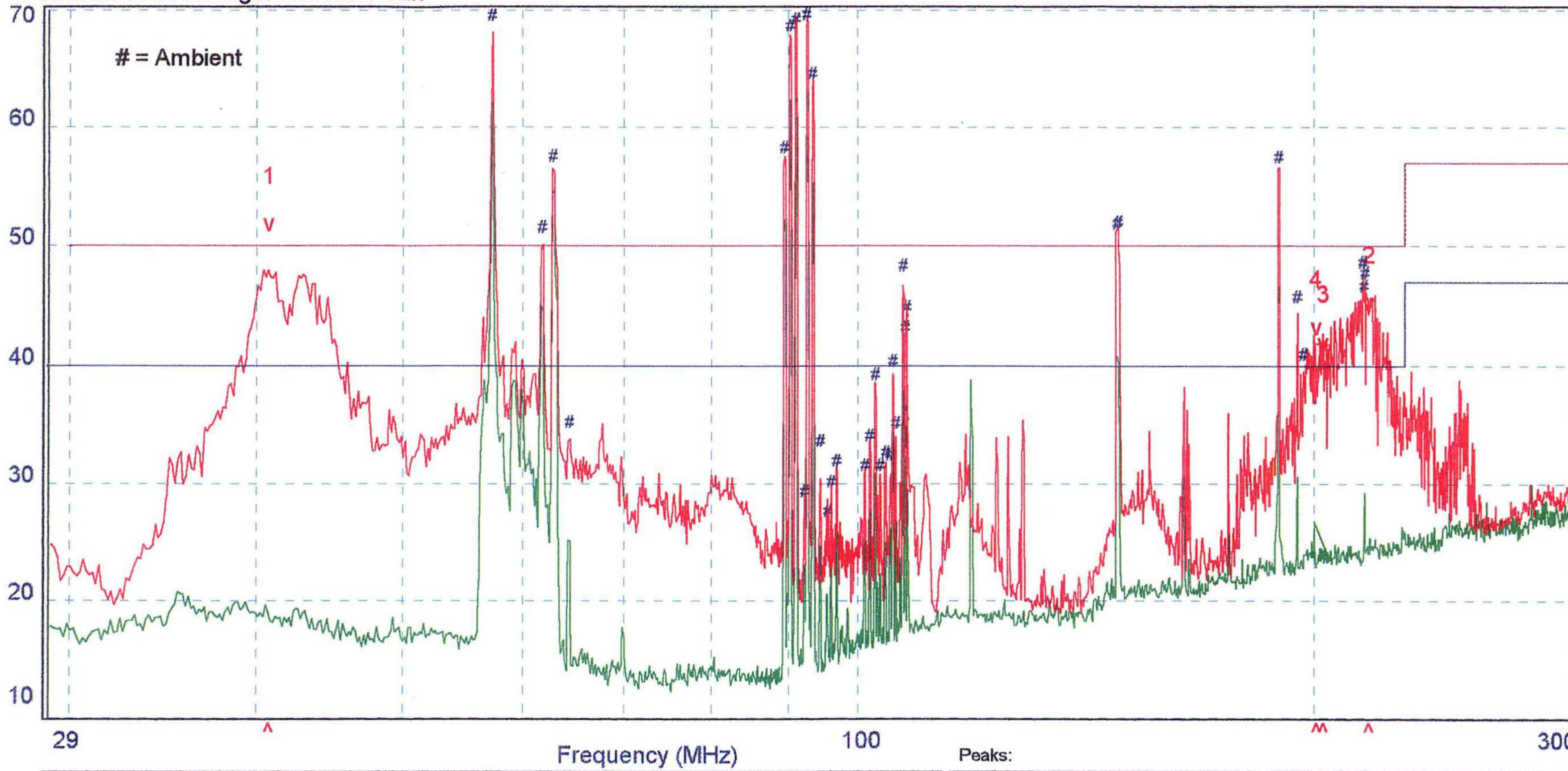
EN55022 Job No:M60732X c:\pcf\CRITE_1.PCF

Electric Field Strength dBuV/m Peak Test Date: 19-07-96 GRAPH No. 1




GLOBAL LIGHTNING TECHNOLOGIES P/L
HPI SERIES 3 INVERTER
HALF LOAD

Peaks:

| No | Freq (MHz) | Peak (dBuV/m) | Qp Val | C22-B3 (dBuV/m) | dL1 (dB) | C22-A3 (dBuV/m) | dL2 (dB) |
|---|---|---|---|---|---|---|---|
| 1 | 40.72 | 51.0 | 43.0 | 40.0 | 3.0 | 50.0 | -7.0 |
| 2 | 217.46 | 44.4 | 30.3 | 40.0 | -9.7 | 50.0 | -19.7 |
| 3 | 202.80 | 41.1 | 29.2 | 40.0 | -10.8 | 50.0 | -20.8 |
| 4 | 200.55 | 42.4 | 28.6 | 40.0 | -11.4 | 50.0 | -21.4 |

Limits:
C22-B3 CISPR 22 CLASS B 3mtr QP LIMITS
C22-A3 CISPR 22 CLASS A 3mtr QP LIMITS

Legend:
Vertical Ambients
EUT ON

Source:
c:\m60732x 67 68 69 70
c:\m60732x 42 43 44 45

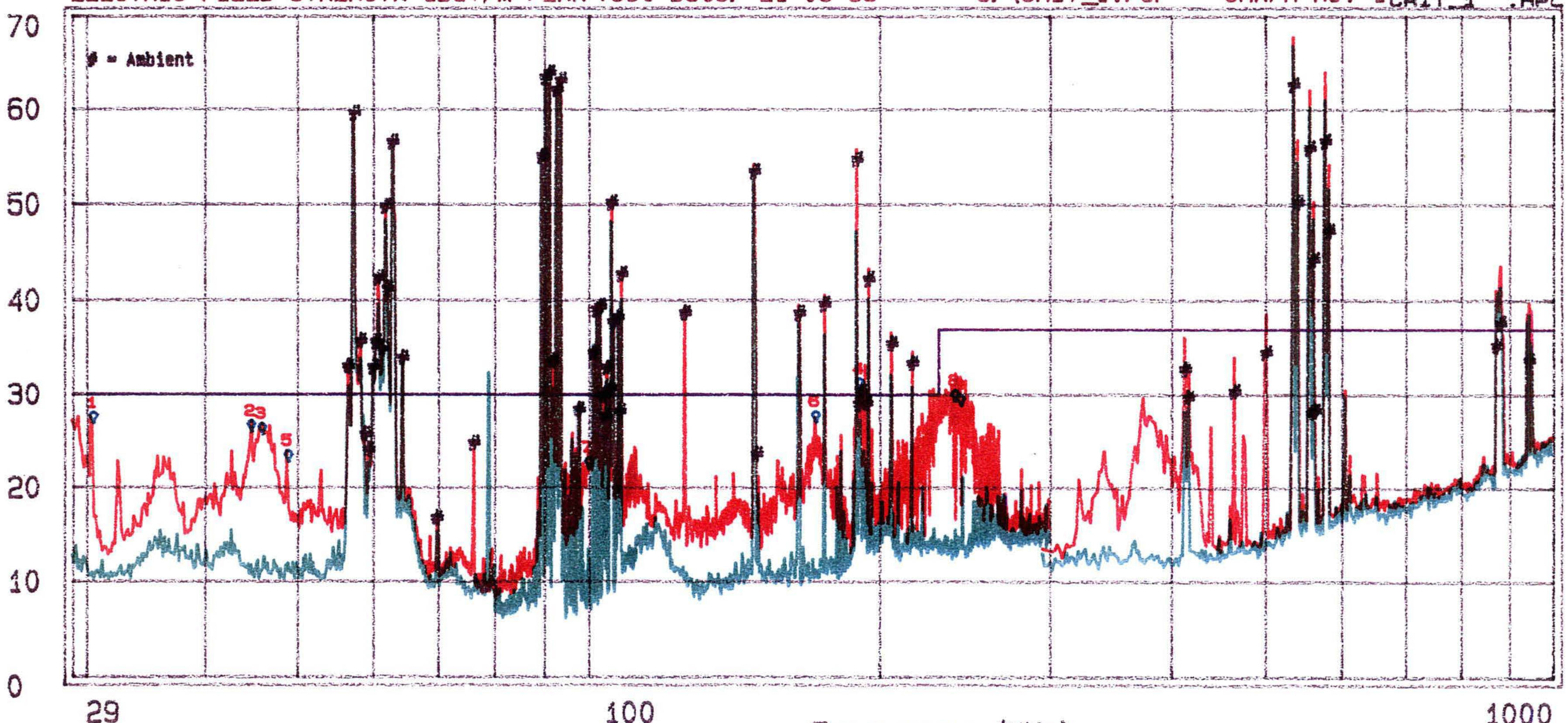
Equipment:STEVE
Transducers: CABLE1_2 BICON_10
Site ID:
Test Officer:

Melbourne- 57 Assembly Drv Tullamarine, 3043, Vic, Australia Ph+(613) 9335 3333 Fax+(613) 9338 9260
Sydney---- 16,6 Gladstone Rd Castle Hill, 2154, NSW, Australia Ph+(612) 899 4599 Fax+(612) 899 4019

EMC Technologies Pty. Ltd. - EMI-EMC Specialists

Unit 2, 40 Assembly Drv, Tullamarine, Vic 3043, Australia Ph. +(61 3) 335 3333 Fax +(61 3) 338 9260

ELECTRIC FIELD STRENGTH dBuV/m PEAK Test Date: 21-09-95 C:\CRIT_1.PCF GRAPH No. 1 CRIT_1 .HPL




GLOBAL LIGHTNING TECHNOLOGIES PTY. LTD.
SINECTEC HP-1 SERIES 2
VERTICAL POLARITY

Limits:
__ 354810MB
AS3548-CLASS B 10m LMTS

Traces:
__ VERTICAL AMBIENTS B:\M50912A
__ EUT ON B:\M50912A

| | |
|---|---|
| 63 | 51 |
| 64 | 52 |
| 65 | 53 |
| 66 | 54 |
| 61 | 60 |

Peaks:

| | Freq. (MHz) | PK (dB) | QP (dB) | AZ deg | TH cm | DQPL1 (dB) | DQPL2 (dB) |
|---|---|---|---|---|---|---|---|
| 1: | 30.465: | 26.6: | 23.6 : | 0 : | 0 : | -6.4 : | |
| 2: | 44.721: | 25.7: | 20.8 : | 0 : | 0 : | -9.2 : | |
| 3: | 45.911: | 25.4: | 20.3 : | 0 : | 0 : | -9.7 : | |
| 4: | 190.740: | 30.4: | 19.2 : | 0 : | 0 : | -10.8 : | |
| 5: | 48.775: | 22.5: | 18 : | 0 : | 0 : | -12 : | |
| 6: | 171.605: | 26.8: | 11.8 : | 0 : | 0 : | -18.2 : | |
| 7: | 99.777: | 21.8: | 10.8 : | 0 : | 0 : | -19.2 : | |
| 8: | 239.686: | 29.1: | 13.9 : | 0 : | 0 : | -23.1 : | |
| 9: | 242.856: | 28.6: | 10.9 : | 0 : | 0 : | -26.1 : | |

Report No: M50912A
Standard: AS3548-B

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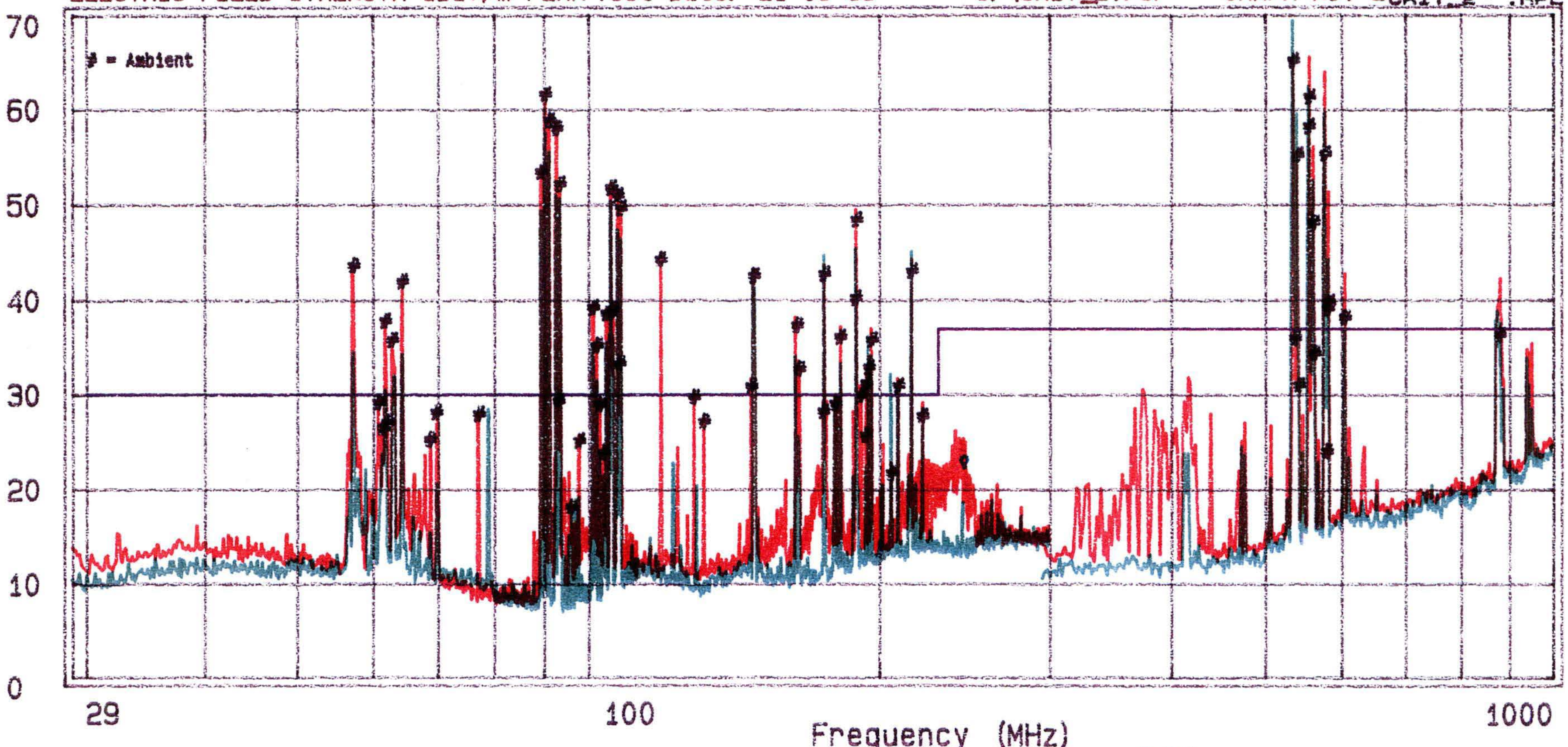
Unit 2, 40 Assembly Drv, Tullamarine, Vic 3043, Australia Ph. +(61 3) 335 3333 Fax +(61 3) 338 9260

ELECTRIC FIELD STRENGTH dBuV/m PEAK Test Date: 21-09-95 C:\CRIT_2.PCF GRAPH No. 2 CRIT_2 .HPL




GLOBAL LIGHTNING TECHNOLOGIES PTY. LTD.
SINECTEC HP-1 SERIES 2
HORIZONTAL POLARITY

Peaks:

| Freq. (MHz) | PK (dB) | QP (dB) | AZ deg | TH cm | DQPL1 (dB) | DQPL2 (dB) |
|---|---|---|---|---|---|---|
| 1: 243.959: | 22.1: | 12.5 : | 0 | : 0 | : -24.5 : | |

Limits:
__ 354810MB
AS3548-CLASS B 10m LMTS

Traces:
__ HORIZONTAL AMBIENTS B: \M50912A
__ EUT ON B: \M50912A

| | |
|---|---|
| 67 | 55 |
| 68 | 56 |
| 69 | 57 |
| 70 | 58 |
| 62 | 59 |

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88

Report No: M50912A
Standard: AS3548-B

different antennas and represent the peak envelope of emissions measured after the equipment has been rotated through 360° and the receive antenna has been scanned over its full height range. These plots are actually taken from a certified test report which declared compliance of this product with the CISPR Class B limits. At this stage of development of the pre compliance test facilities, the car park OATS facility was not operational and these compliance results were obtained after only performing conducted emissions pre-compliance checks. Later cross checks on the car park OATS indicated emission levels that were generally only just discernible amongst the ambient noise. This concurred with the compliance measurements but the measurements did not provide any significant verification of the car park OATS facility due to the low signal levels involved. The general feeling was that, if anything, the levels measured in the car park OATS were less than those measured on the compliance test site. Indeed, the same indication was given from a second product with low radiated emission levels (a DC-DC converter) which also achieved certified compliance with the CISPR Class B limits.

The compliance emission profile shown CRIT_1.PCF and CRIT_2.PCF indicated that the worst case emissions were vertically polarised (mainly in the 30 - 50MHz range) and this was isolated as radiation from the connecting cables which hung vertically from the rear of the unit and was possibly due to power switching diode "snap-off". These peaks occurred at a 1m antenna height with the rear of the unit facing the antenna (ie. for a direct line coupling path from the connecting cables to the antenna). High frequency emissions above 200 MHz were found to be due to the support rectifier SMPS (which only complied with CISPR Class A limits) and this was turned off and the unit run from batteries for scans in the higher frequency range. The horizontally polarised emissions were generally very low level with the maximum occurring at the maximum antenna elevation.

The pre-compliance results shown for the test case inverter in Figures 7.3.4 - 7.3.6 indicate significant radiated emission levels for vertical polarisation in the 30 - 50MHz range in Band C. The large humps in the peak emission envelope between 150MHz and 250MHz are due to the operation of the support rectifier and can be effectively ignored. This particular unit had a "floating" output topology which was significantly different to the previous Class B compliant inverter product. Apart from the obvious frequencies of concern, the emissions envelope approaches the limit line for various frequencies for both horizontal and vertical polarisations. Very low emission levels are indicated in Band D.

At the stage that these measurements were taken, analysis of site attenuation or calibration verification measurements had not been conducted. Thus, very little confidence was attached to the pre-compliance radiated emissions measurements made and it was decided to submit for compliance testing in spite of the indication of possible problems. With the benefit of hindsight, this was not a wise decision but did provide useful data for this study.

An initial, vertically polarised, band C scan of the test case inverter at the remote compliance OATS (c:\pcf\CRITE_1.PCF) realised my "worst fears". That is, that the pre-compliance measurements made, were sensible and the "suspected" emission problem in the 30 - 50MHz range was a real problem. It should be noted that the plot shown for the remote OATS was actually taken with the unit running half load and at full load the emissions were a few dB higher. Modifications to the size of Y-capacitors on the output load lines (which was the main offending cable) improved the emissions enough to gain compliance with the Class A limits but more design modifications are required for Class B compliance.

Comparison of the pre-compliance results with the accurate remote OATS scan shows that the problem emission levels measured in the car park were lower than those measured at the accurate site. A problem with the design of the pre-compliance turntable was also identified with the connection cables wrapping around the rotator shaft and not remaining in a fixed vertical arrangement. The physical effect of this is to reduce the exposure of the connecting cables for radiation of vertically polarised emissions and increase the horizontally polarised exposure as the equipment is rotated. This may contribute to the lower emission levels measured for vertical polarisation (and the higher levels for horizontal polarisation) on the car park OATS. A new turntable is on the drawing board which will have an EUT top surface and a support equipment shelf which will be rotated as a single entity.

A more detailed analysis of the accuracy of measurements on the car park OATS is covered in the following section dealing with site attenuation and antenna factor calibration.

## *7.4 Verification of Pre-Compliance OATS and Antenna Factors*

### *7.4.1 Normalised Site Attenuation Measurements*

Detailed procedures are outlined in ANSI C63.4-1992 on how to perform measurements of the Normalised Site Attenuation (NSA) of an Open Area Test Site (OATS). A tolerance of ±4dB is allowed on the measured NSA compared with the ideal figure for an OATS to be used for certified compliance testing. As the purpose of the "in-house" test site described here was to perform pre-compliance confidence checks, an abbreviated Site Attenuation measurement procedure using discrete frequencies and available equipment was carried out in order to identify any gross site anomalies.

The basic measurement procedure for site attenuation is to use a set up similar to that indicated in Figure 7.1.

Two antennas are set up on the test site at the relevant test distance (which in this case is 3m). A signal generator is located at the transmit antenna which is located where the EUT normally sits. The second antenna is used as a receive antenna and is located on the mast normally used for measuring radiated emissions on the OATS. The NSA measurement procedure requires two different measurements of the voltage received at the spectrum analyser ($V_R$). The first measurement is made with the coaxial cables disconnected from the two antennas and connected together using an adaptor. The signal generator output level is then measured directly on the analyser ($V_{DIRECT}$). The second reading of $V_R$ is taken with the coaxial cables reconnected to their respective antennas (which are orientated for either horizontal or vertical polarisation) and the receive antenna scanned in height and the maximum received signal level is measured

($V_{SITE}$). These two measurements are made with the signal generator source voltage kept constant.

The Normalised Site Attenuation (NSA) is then given by;

$$A_N = V_{DIRECT} - V_{SITE} - AF_T - AF_R - \Delta AF_{TOT}$$

where;
$A_N$ = Normalised Site Attenuation
$V_{DIRECT}$ = Direct measurement of signal level
$V_{SITE}$ = Peak signal level at the receive antenna
$AF_T$ = Antenna factor of transmitting antenna
$AF_R$ = Antenna factor of receiving antenna
$\Delta AF_{TOT}$ = Mutual impedance correction factor

Performing the measurement in this way negates the need to measure the cable losses separately as they are common to both the direct and site measurements.

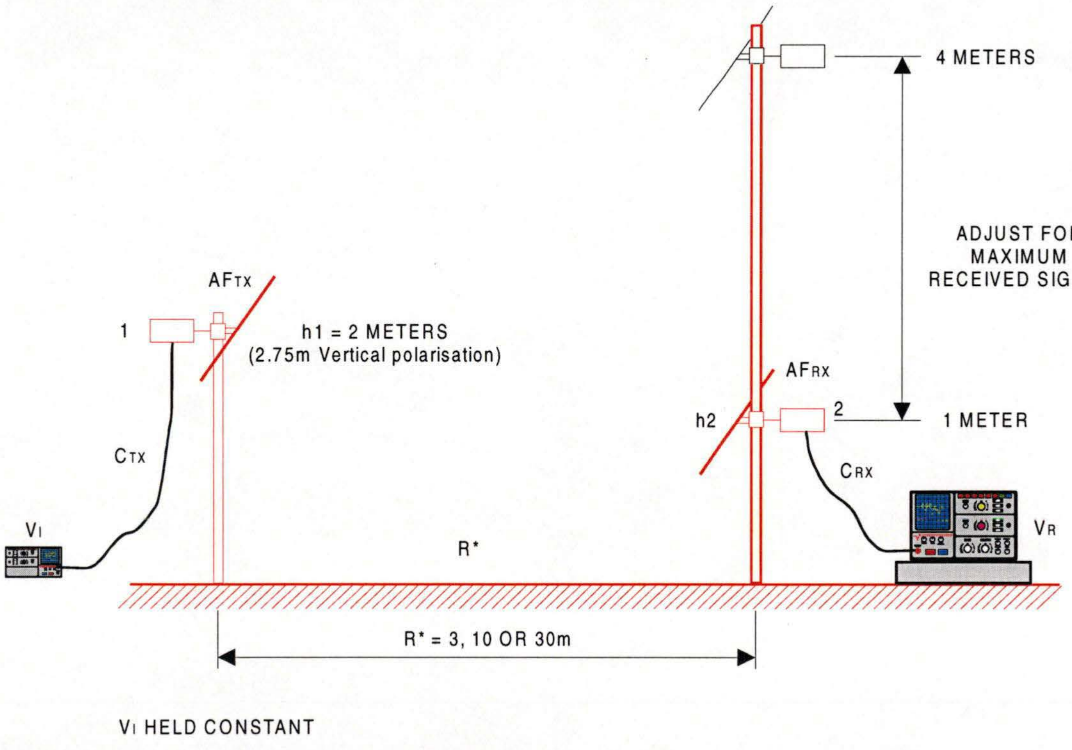


**Figure 7.1 - Site attenuation measurement setup**

The theoretical NSA values for an ideal site are tabulated in ANSI C63.4-1992 and the reader is directed to this standard for a complete theoretical discussion of the NSA measurement procedure. Also tabulated in this standard are the mutual impedance correction factors when using two antennas spaced 3m apart and these apply from 30MHz to 180MHz. Beyond 180MHz the mutual impedance correction factor is zero.

In order to perform NSA measurements for a certified compliance site, accurate antenna factors are required. The corollary to this is that in order to measure antenna factors an "ideal" OATS is required or the site attenuation figures must be accurately known. With the equipment available for the pre-compliance site, both of these factors were "uncertain". Thus in order to get a first order verification of the site attenuation and the antenna factors of the broadband receive antennas, two test procedures were proposed based on a "cut down" versions of the NSA and antenna calibration procedures detailed in ANSI C63.4 - 1992 and ANSI C63.5 - 1988 respectively.

The site attenuation measurements were made using the tuned dipole set described previously. It was assumed that these antennas represented "reference dipoles" as specified in the ANSI standards and thus that the antenna factors tabulated for such dipoles applied to the antennas (the manufacturers data indicated that this was the case within a few dB). Thus by using these "known" antennas it was possible to make site attenuation measurements at two spot frequencies where the dipoles overlapped (i.e. where matched sets could be configured). The frequencies chosen for these measurements were 150MHz and 400MHz. The results obtained are shown in Table 7.1 which is a copy of the Site Attenuation Worksheet provided in ANSI C63.4 - 1992.

These results indicate excellent correlation (within ± 1dB) to the "ideal" site at 150MHz (horizontal and vertical polarisations) which is well within the ±4dB specification for a compliance measurement site and much better than expected given the assumptions made and the various sources of uncertainty present. The results at 400MHz were not as good however, with a +7dB deviation from the ideal for horizontal polarisation and +5dB for the vertical polarisation. It would be easy to find a number of possible sources of error that could account for this (see Figure 7.2) but one of more likely causes is the discontinuities that are known to exist in the ground plane (due to broken solder joints) which are of dimensions that are significant compared to a wavelength at 400MHz.

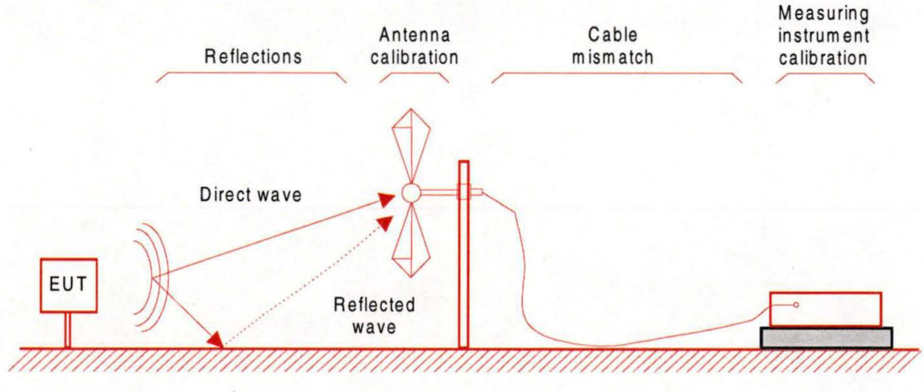


**Figure 7.2 - OATS Testing and Sources of Error.**

# Table 7.1 - Spot Frequency NSA Measurements
## Pre-Compliance OATS

| (1) Frequency (MHz) | (2) Polarization H or V | (3) $V_{DIRECT}$ dB ($\mu$V) | (4) $V_{SITE}$ dB ($\mu$V) | (5) $\Delta AF_{TOT}$ See Table 4 dB | (6) Adjusted Site Attenuation dB | (7) $AF_{TX}$ dB (1/m) | (8) $AF_{RX}$ dB (1/m) | (9) $A_N$ (NSA) Measured dB $(1/m)^2$ | (10) $A_N$ (NSA) Theoretical dB $(1/m)^2$ | (11) Deviation dB |
|---|---|---|---|---|---|---|---|---|---|---|
| 150 | H | 102·8 | 84·2 | -0·4 | 19 | 12·1 | 12·1 | -5·2 | -6·3 | 1·1 |
| 400 | H | 105·5 | 71·8 | 0 | 33·7 | 20·6 | 20·6 | -7·5 | -14·9 | 7·4 |
| | | | | | | | | | | |
| 150 | V | 102·8 | 81·4 | -0·4 | 21·4 | 12·1 | 12·1 | -2·8 | -2·0 | -0·8 |
| 400 | V | 105·5 | 71 | 0 | 34·5 | 20·6 | 20·6 | -6·7 | -11·4 | 4·7 |
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Note:
(6)=(3)–(4)–(5)
(9)=(6)–(7)–(8)
(10)=See Tables 1–3
(11)=(10)–(9)

REMARKS Measurement Distance R=3m
(h₁) Tx Antenna Height = 2m (H), 2·75m (V)
(h₂) Rx Antenna Height = 1–4m (Scanned)

# Table 7·2 - Spot Frequency AF/NSA Measurements Pre-compliance OATS - Horizontal Polarisation

| (1) Frequency (MHz) | (2) Polarization H or V | (3) $V_{DIRECT}$ dB (μV) | (4) $V_{SITE}$ dB (μV) | (5) $\Delta AF_{TOT}$ See Table 4 dB | (6) Adjusted Site Attenuation dB | (7) $AF_{TX}$ dB (1/m) | (8) $AF_{RX}$ dB (1/m) | (9) $A_N$ (NSA) Measured dB $(1/m)^2$ | (10) $A_N$ (NSA) Theoretical dB $(1/m)^2$ | (11) Deviation dB |
|---|---|---|---|---|---|---|---|---|---|---|
| 30 | H | 104·5 | 74·2 | 0·6 | 29·7 | -1 | 14·7 | 16·0 | 11·0 | +5·0 |
| 90 | H | 102·8 | 86·2 | -0·4 | 17·0 | 9·5 | 10·4 | -2·9 | -1·8 | -1·1 |
| 150 | H | 102·8 | 84·2 | -0·4 | 19·0 | 13·5 | 13 | -7·5 | -6·3 | -1·2 |
| 250 | H | 101·3 | 77·4 | 0 | 23·9 | 16·5 | 19 | -11·6 | -10·6 | -1·0 |
| 400 | H | 105·5 | 71·8 | 0 | 33·7 | 20·5 | 21 | -7·8 | -14·9 | 7·1 |
| 800 | H | 101·3 | 63·5 | 0 | 37·8 | 27 | 27 | -16·2 | -20·8 | 4·6 |

Note:
(6)=(3)–(4)–(5)
(9)=(6)–(7)–(8)
(10)=See Tables 1–3
(11)=(10)–(9)

REMARKS Measurement Distance R=3m
($h_1$) Tx Antenna Height = 2m
($h_2$) Rx Antenna Height = 1-4m (Scanned)

# Table 7·3 - Spot Frequency AF/NSA Measurements
## Pre-compliance OATS - Vertical Polarisation

| Rx Antenna Scan (m) | (1) Frequency (MHz) | (2) Polarization H or V | (3) $V_{DIRECT}$ dB (μV) | (4) $V_{SITE}$ dB (μV) | (5) $\Delta AF_{TOT}$ See Table 4 dB | (6) Adjusted Site Attenuation dB | (7) $AF_{TX}$ dB (1/m) | (8) $AF_{RX}$ dB (1/m) | (9) $A_N$ (NSA) Measured dB $(1/m)^2$ | (10) $A_N$ (NSA) Theoretical dB $(1/m)^2$ | (11) Devia-tion dB |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2·75-4 | 30 | V | 104·5 | 76·5 | 0·6 | 27·4 | -1 | 14·7 | 13·7 | 12·4 | 1·3 |
| 1·08-4 | 90 | V | 102·8 | 81·1 | -0·4 | 22·1 | 9·5 | 10·4 | 2·2 | 1·5 | 0·7 |
| 1-4 | 150 | V | 102·8 | 81·4 | -0·4 | 21·8 | 13·5 | 13 | -4·7 | -2·0 | -2·7 |
| 1-4 | 250 | V | 101·3 | 72·1 | 0 | 29·2 | 16·5 | 19 | -6·3 | -7·0 | 0·7 |
| 1-4 | 400 | V | 105·5 | 71·0 | 0 | 34·5 | 20·5 | 21 | -7·0 | -11·4 | 4·4 |
| 1-4 | 800 | V | 101·3 | 62·4 | 0 | 38·9 | 27 | 27 | -15·1 | -17·4 | 2·3 |

Note:
(6)=(3)–(4)–(5)
(9)=(6)–(7)–(8)
(10)=See Tables 1–3
(11)=(10)–(9)

REMARKS: Measurement Distance R=3m
($h_1$) Tx Antenna Height = 2·75
($h_2$) Rx Antenna Height = 2·75-4m → 1-4m
(Scanned as shown).

### *7.4.2 Antenna Factor Verification*

The second OATS verification procedure carried out was to use the Normalised Site Attenuation measurement procedure to check the antenna factors of the broadband antennas used for making radiated emission measurements. The underlying assumption in this procedure is that the OATS is ideal and the variations measured are due to inaccuracies in the antenna factors. While this is not a particularly sound experimental methodology, particularly considering the NSA inaccuracy measured at 400MHz above, it does at least provide a "first order" verification for the antennas used.

For these measurements, tuned dipoles (from the set described previously) were used for the transmitting antenna and the broadband antennas were used as the receivers. The manufacturer calibration was used for the antenna factors in each case. Spot frequencies that did not coincide with large ambient signals were selected and NSA measurements were carried out. The results obtained are shown in Table 7.2 (horizontal polarisation) and Table 7.3 (vertical polarisation). The assumption here is that the site is 'ideal' and the errors between the measured and theoretical site attenuation values are due to errors in the antenna factors.

Note: The circular polarisation AFs quoted for the log spiral antenna were corrected by 3dB as required. Also, for vertical polarisation, the transmit antenna height is set at 2.75m and the minimum scan height of the receive antenna is varied from 2.75 at 30MHz down to 1m at 150MHz (as required in ANSI C63.4 - 1992 and shown in Table 7.3) due to the physical length of the antenna elements required for a half wavelength dipole at lower frequencies.

The results obtained generally indicate a good correlation between the measured and theoretical results; within ±5dB with the exception of 7dB for horizontal polarisation at 400MHz. Coupled with the results obtained with the dipole pair, this would seem to confirm that there is a site anomaly at around 400MHz for horizontally polarised emissions which is probably related to the ground plane discontinuities discussed before. Also the 5dB increase in attenuation (above the theoretical value) at 30MHz (horizontal) could be an indication of the inadequacies of the width of the ground plane used as the dipole elements actually extend beyond the ground plane boundaries at this frequency.

## *7.5 Immunity Testing*

A copy of a certified test report verifying the compliance of an inverter product with the requirements of EN 50081-1 (the generic immunity standard for "residential, light industrial and commercial environments") is attached for reference. Pre-compliance, in-house tests provided confidence that the immunity levels and performance criteria recorded were going to be achieved for most of the tests.

The most susceptible aspect of this product was in its immunity to radiated RF fields where some alarm states were flagged during tests at 10V/m. These alarm LEDs were reset after removal of the field and thus Performance Criteria 2 (or B) was achieved. Further investigation into the cause of this susceptibility is being conducted in the hope of further improving the EMC immunity of this unit.

**EMC Technologies**
**Global Product Certification**

**EMC Technologies Pty. Ltd.**
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Australia.

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# EMC VERIFICATION REPORT
# to
# EN50082-1
# EMC DIRECTIVE 89/336/EMC

**Report No. M51029X**

Manufacturer. **Global Lightning Technologies Pty Ltd**
Test Sample **Inverter**
Model. **HPI Series 2**

Date. **16 November 1995**

NATA
Reg. 5292

# EMC VERIFICATION TESTS
# to
# EN50082-1

| | |
|---|---|
| **Report No.:** | M51029X |
| **Test Sample.:** | Inverter |
| **Model:** | HPI Series 2 |
| **Test Date:** | 16 October 1995 |
| **Manufacturer:** | Global Lightning Technologies Pty Ltd<br>Technopark, Dowsings Point<br>Hobart Tas 7001<br>Ph. +(6102) 730 066<br>Fax. +(61 02) 730 399 |
| **Test Standard:** | EN50082-1 Immunity<br>IEC 801-2. 1991/EN61000-4-2<br>IEC 801-3 1984<br>IEC 801-4· 1988/EN61000-4-4<br>IEC 801-5 Draft/EN61000-4-5 |
| **Test Officers:** | Matthew Lawrence |
| **Tested for:** | Global Lightning Technologies Pty Ltd |
| **Responsible Party:** | ____________<br>Peter Johnson.<br>Global Lightning Technologies Pty Ltd |
| *Attestation:* | *I hereby certify that the device(s) described herein were tested as described and that the data included is that which was obtained during such testing.* |
| | ____________<br>Chris Zombolas<br>Technical Director<br>EMC Technologies Pty Ltd. |

Reg. 5292

# EMC VERIFICATION TESTS
# to
# EN50082-1
# on the
# Inverter

**Report No. M51029X**

**16 November 1995**

## CONTENTS

# EMC VERIFICATION TESTS
# to
# EN50082-1

**EMC Technologies Report No. M51029X**

## 1. TEST SUMMARY.

This report is intended to document conformance of the Inverter with the Electromagnetic Compatibility (EMC) requirements of **EN50082-1** The results of the EMC tests are provided including details of the test methods and the instrumentation used for the tests The test sample complied with the requirements of the European EMC Directive 89/336/EEC.

**EN50082-1 (IEC 801-2, 3 & 4)**

- **IEC 801-2:1991 Immunity to Electrostatic Discharge.**

| | |
|---|---|
| Contact Discharge: | Complied to level 3(±6 kV), no response, Criteria 1. |
| Air Discharge | Complied to level 3 (±8 kV), no response, Criteria 1 |
| Indirect Contact Discharge | Complied to level 3 (±8 kV), no response, Criteria 1 |

- **IEC 801-3:1984 Immunity to Radiated Fields.**

Complied, level 2 (10V/m fields) over the range 27 to 1000 MHz, Criteria 2

- **IEC 801-4:1988 Immunity to Electric Fast Transient Bursts.**

| | |
|---|---|
| Auxiliary AC input: | Level 4, ±4.0 kV, Complied, Criteria 2 |
| | Level 3, ±2 0 kV, Complied, Criteria 1. |
| Other cables: | Level 4, ±4.0 kV, Complied, Criteria 2 |
| | Level 3, ±2 0 kV, Complied, Criteria 1 |

- **IEC 801-5: (Draft) Immunity to High Voltage Surges.**

Complied, Level 4 (4kV surges), Criteria 1.

## 2. APPLICABLE REGULATIONS and STANDARDS.

### 2.1 EN50082-1: 1992
*Electromagnetic Compatibility - Generic Immunity Standard. Part 1. Residential, Commercial and light Industry.*

### 2.2 IEC 801-2: 1991 / EN 61000-4-2: 1995
*Electromagnetic Compatibility for Industrial Process Measurement and control Equipment Part 2: Electrostatic Discharge Requirements.*

**2.3 IEC 801-3: 1984**
*Electromagnetic Compatibility for Industrial Process Measurement and control Equipment Part 3: Radiated Electromagnetic Field Requirements.*

**2.4 IEC 801-4: 1988 / EN 61000-4-4: 1995**
*Electromagnetic Compatibility for Industrial Process Measurement and control Equipment Part 4: Electrical Fast Transient/Bursts Requirements.*

**2.5 IEC 801-5: (Draft) / EN 61000-4-5: 1995**
*Electromagnetic Compatibility for Electrical and Electronic Equipment. Part 5: Surge Immunity Requirements.*

## 3. TEST SAMPLE DETAILS & PERFORMANCE CRITERIA

### 3.1 Test Sample Functional Description

The Equipment Under Test (EUT) was identified as follows.

| | |
|---|---|
| Manufacturer | GLOBAL LIGHTNING TECHNOLOGIES PTY LTD |
| Test Sample | SINETEC HPI-SERIES 2 |
| Model. | HPI-2 12/48-240/50T |
| Serial No.. | 14429001 |
| Cat No | 400310 |

The SINETEC HPI-SERIES 2 is a high performance 48VDC-240VAC, 50Hz sine wave inverter It is designed to power 240VAC, 50Hz equipment using a normal 48VDC supply as the power source The design employs the latest high frequency switch-mode power conversion techniques to achieve 1kW of output power (1200VA @ 0 8 power factor) in a compact 3RU high, 19 inch (483mm rack mounted unit weighing 16kg.

The unit is capable of supplying loads of any power factor and in particular has been designed to supply the high crest factor currents drawn by computing and other electronic equipment. Under any load condition, within the rating of the unit, an output voltage sine wave with very low distortion is maintained. The power supply for the tests consisted of a 50A, 48VDC rectifier connected to two parallel banks of 4x6 5AH 12V sealed lead acid batteries in series to give a 13AH, 48V battery

### 3.2 Test Sample Performance for EN50082-1 Tests

**Criteria 1:** Normal performance within the specification limits.

**Criteria 2:** Temporary degradation or loss of function or performance which is self recoverable

**Criteria 3:** Temporary degradation or loss of function or performance which requires operator intervention or a system reset.

**Criteria 4:** Degradation or loss of function which is not recoverable, due to damage of equipment, components, software or loss of date.

## 4. IMMUNITY TO ESD: IEC 801-2: 1991

### 4.1 Test Procedure - ESD

This test was performed with the EUT setup as detailed in section 3 of this report. The following points of the EUT were probed with ESD levels of up to ±6 kV (level 3) for contact and up to ±8kV (level 3) for Air Discharge The performance criteria of section 3.4 was used to evaluate immunity of the inverter to ESD

### 4.2 Contact Discharges.

**Indirect Contact Discharges: Level 3 (±6kV)**
No effect on the operation of the unit
**Result:** Complied criteria 1.

**Direct Contact Discharges: Level 3 (±6kV)**
No effect on the EUT
**Result:** Complied criteria 1

### 4.3 Air Discharges.

**Direct Air Discharges: Level 3 (±8kV)**
No effect on the EUT
**Result:** Complied criteria 1.

### 4.4 Conclusion for ESD Tests.

The Inverter complied with the immunity requirements for Electrostatic Discharge at Level 3, Criteria 1.

## 5. IMMUNITY to RADIATED RF FIELDS: IEC 801-3.

### 5.1 Test Procedure

The EUT was set up in the shielded test chamber in accordance with section 3 of this report. The test equipment were external to the chamber. The EUT was radiated over the range 27-1000 MHz at a field strength of at least 10V/m The signal was 80% AM modulated by a 1kHz tone The front and back of the EUT were tested. The scan rate was approximately 40 minutes per decade using frequency steps of less than 1% A dwell time of 3 seconds was used

**5.2 Test Results**
The EUT latched a load overcurrent indicator but continued to operate normally without user intervention.

**5.3 Conclusion.**
The Inverter complied with criteria 2 when subjected to radiated fields of >10 V/m test over the range 27 MHz to 1000 MHz.

## 6. IMMUNITY to ELECTRICAL FAST TRANSIENT: IEC 801-4

**6.1 Test Procedure**
The EUT was subjected to conducted transients tests in accordance with IEC 801-4 1988 by injection onto the auxiliary AC input cable of the Inverter, and by utilising a cable clamp to couple to the dc input, alarm output and REPO (Remote Emergency Power Off) cables.

**6.2 Results of Electrical Fast Transient (EFT/B) Burst Tests.**
Level 3. The EUT exhibited no response to the transient over a five minute period.

Level 4· The EUT latched load overcurrent and auxiliary AC input fault indicators on positive polarity for the active and neutral lines of the auxiliary AC input, and when coupling to the alarm output cables. Performance was not degraded and the inverter continued to operate normally

**6.3 Conclusions : EFT/B Tests.**
The EUT complied with criteria 1 for level 3 (±2kV injection, ±1kV coupling clamp)

The EUT complied with criteria 2 for level 4 (±4kV injection, ±2kV coupling clamp)

## 7. IMMUNITY to HIGH VOLTAGE SURGES: IEC 801-5

**7.1 Test Procedure**

The EUT was setup and operated as detailed in section 2 of this report The EUT was tested with a IEC 801-5 Interference Simulator with a repetition rate of 1 pulse per minute for 10 minutes Both differential mode (2 0kV) and common mode (4 0kV) were applied to both supply lines The surges were applied at phase angles of 0, 90, 180, 270 deg The surge generator was fully compliant with the IEC 801-5 (Draft) including the 2 ohm source impedance

**7.2 Results of High Voltage Surges: IEC 801-5**
The EUT complied with criteria 1 when subjected to 4 0 kV common mode surges and 2.0 kV differential mode surges.

### 7.3 Conclusion : IEC 801-5

The EUT when subjected to the high voltage fast surges complied with Criteria 1

## 8. CONCLUSIONS

The Inverter was tested in accordance with the EN50082-1 and IEC 801-5 immunity requirements The test sample complied with EMC test requirements as required by the European EMC Directive 89/336/EEC

# APPENDIX A

## TEST and MEASUREMENT INSTRUMENTATION DETAILS

| EQUIPMENT TYPE | MAKE/MODEL SERIAL NUMBER | LAST CAL. DD/MM/YY | DUE DATE DD/MM/YY | CAL. INTERVAL |
|---|---|---|---|---|
| **EMI RECEIVER** | HP8574B MIL-STD 462 Bandwidths Sn 314A01297 | 27/09/94 | 27/09/95 | 1 YEAR *4 |
| **SPECTRUM ANAL** | HP8593E Sn 3249A00402 | 06/02/95 | 06/02/96 | 1 YEAR *4 |
| **POWER METER** | HP435A Sn.1733A05847 | 19/10/95 | 19/04/96 | 6 MONTH *4 |
| **POWER SENSOR** | HP8481H Sn 1545A01634 | 21/09/95 | 21/09/96 | 1 YEAR *4 |
| | HP8484A Sn 1635A00768 | 21/09/95 | 21/09/96 | 1 YEAR *4 |
| **SIG GENERATOR** | HP8657A 0.1-1040MHz Sn 283U00865 | 20/4/95 | 20/4/96 | 1 YEAR *4 |
| | HP34401A DIGITAL VOLT METER | 30/8/95 | 30/8/96 | 1 YEAR *4 |
| | Sn. 3146A09424 | | | |
| | EMCO 3109 BICONICAL | 26/8/95 | 26/8/96 | 1 YEAR *3 |
| | 20 - 300MHz Sn. 2660 | | | |
| | EMCO 3146A LOG PERIODIC | 26/8/95 | 26/8/96 | 1 YEAR *3 |
| | 300 -1000MHz Sn. 1205 | | | |
| | | | | |
| **Reference Dipole** | EMCO 3121C DIPOLE SET | 03/05/94 | 03/05/97 | 3 YEAR *5 |
| | 30-1000 MHz Sn. 834 | | | |
| | EMCO 3121C DIPOLE SET | 03/05/94 | 03/05/97 | 3 YEAR *3 |
| | 30-1000 MHz Sn. 835 | | | |
| | | | | |
| **ATTENUATORS:** | HP8496B 0-110 dB. DC-18 GHz Sn 2827A18252 | 10/11/94 | 10/11/95 | 1 YEAR *4 |
| | HP8494B 0-11 dB. DC-18 GHz Sn 2812A20927 | 10/11/94 | 10/11/95 | 1 YEAR *4 |
| **LIMITER /BPF:** | HP11867A 9 kHz-220 MHz Sn 3107A00857 | 27/10/94 | 27/10/95 | 1 YEAR *3 |
| **E FIELD SENSORS** | IF EFS-1 Sn. 1489_F | 7/11/94 | 7/11/95 | 1 YEAR *6 |
| | IFI LMDT Sn. 882-B | | | |
| | IFI LDI Sn 576-C | | | |
| **ESD GENERATOR** | Schaffner NSG432 Sn. 0110 | 19/05/95 | 19/05/96 | 1 YEAR * |
| **EFT/B GEN** | Schaffner NSG1025 Sn. 5049322 Schaffner CD125 Clamp Sn 356-9329 | 03/06/95 | 03/06/96 | 1 YEARS *7 |

Note *1. Calibration not required since output is measured with other calibrated instrument
Note *2 Manufactured per MIL-STD-462, Manufacture's calibration data supplied.
Note *3. In-house calibration. Refer to QM.
Note *4. NATA calibration by Hewlett-Packard (Aust) Ltd.
Note *5 National Measurements Laboratory (NML) calibration
Note *6 Australian Radiation Laboratory calibration.
Note *7 Schaffner (manufacturers ) calibration.

## RF AMPLIFIERS

| | | | | |
|---|---|---|---|---|
| **RF AMPLIFIERS** | AR 150L 0 01-220MHz @ 150 WATTS Sn 12097 | | | Not required |
| | AR 100W 1000M7 20-1000MHz 100 W | | | Not required |
| | MPD 0110- 8L Sn 5172-1 | | | |
| | 1-1000 MHz @ 8 Watts | | | Not required |

## TEST SITES

| | | | | |
|---|---|---|---|---|
| **SHIELDED ROOM / TEST LABORATORY** | 8.8m X 5.8m X 3 1m Test Chamber | 10/12/94 | 10/12/95 | 1 YEAR |
| **OPEN AREA TEST SITE** | 3/10 Metre site<br>1-4 metre antenna mast.<br>1.2 metre/400 kG Turntable.<br>(Situated at Glenlyon, near Daylesford, Victoria.) | 2/9/95 | 2/9/96 | 1 YEAR |

## 8. Conclusion

Electromagnetic Compatibility is no longer solely a discipline of interest for research purposes and the military. Electromagnetic **in**compatibility costs money in equipment failures and loss of service and can sometimes have safety implications. Regulations and legislation **mandating** EMC in the commercial world are no longer a pipe dream but are here, now! Today's electrical and electronic engineer needs to be aware of the fundamentals involved with achieving EMC as well as understanding the scope of the emerging regulations in this area.

This thesis has outlined the principles of EMC, detailed the requirements of the latest standards and regulations and introduced some of the design techniques that can be utilised to achieve EMC. The fundamentals of EMC measurements have been outlined and the requirements for a practical and economic EMC pre-compliance test facility have been specified. Finally, measurements made using the pre-compliance test facilities described have been compared with similar measurements made at a NATA calibrated test facility and some fundamental calibration measurements were made on the pre-compliance Open Area Test Site (OATS). These practical measurements enabled an estimation of the measurement accuracy (and thus the usefulness) of the pre-compliance test facilities.

### *8.1 Summary of Results*

Whilst it would not be appropriate to draw too many conclusions from the in-exhaustive measurements made in this study, the indication is that radiated emission measurements made on the pre-compliance OATS with the broadband antennas and measuring equipment available should be accurate to within about ±5dB of those made in certified compliance tests. Caution is indicated at low frequencies (around 30MHz) where the pre-compliance measured level may be up to 5dB down compared to the actual level. Around 400MHz the measured values may be up to 7dB down. Generally, if a 5dB compliance margin is indicated on pre-compliance radiated emission measurements, then compliance can be expected with a high degree of confidence. In general, the initial "10dB uncertainty target" for radiated emissions would appear to have been met and better results are expected with future improvements to the OATS facility. These estimates do not include allowances for differences in the set up and configuration of the Equipment Under Test (EUT).

The in-house pre-compliance measurements made for conducted emissions correlated extremely well to identical certified tests and with the use of accurate (non conservative) transducer calibration factors, the results obtained from these measurements should be accurate to within ±2dB.

Immunity tests are more subjective but similar equipment performance was observed for the in-house tests conducted as was reported during compliance testing.

### *8.2 Scope for Further Investigation and Improvement*

The scope for investigation of the effectiveness of various design techniques for achieving EMC is enormous. Studies into shielding effectiveness for various enclosures and the effect of RF ground impedances in achieving EMC are two fields of study in their own right. The development of standards and regulations is continually evolving and the status quo needs to be continually reviewed.

As far as the pre-compliance test facilities established are concerned, there is scope for further improvements to the OATS and associated apparatus for measuring radiated field emissions. Plans for incremental improvements to this facility are in place.

The immunity testing facilities established are extensive and virtually complete with the only significant capability deficiency being radiated RF field immunity testing. Some further development is planned in this area to at least be able to reproduce spot frequency susceptibilities identified during compliance testing.

# 9. References


[1] Bond A.E.J. (DTI) 1991, 'Implementation of the EMC Directive in the UK', *EMC 91 - Direct to Compliance, ERA Technology Conference, Heathrow, 1991*, ERA Technology

[2] International Electrotechnical Commission Standard, *IEC50 (161) Glossary of electrotechnical, power, telecommunication, electronics, lighting and colour terms: Electromagnetic compatibility*

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